IC 8832

Bureau of Mines Information Circular/1980

Automatic Fire Protection Systems for Surface Mining Equipment

By William H. Pomroy and Kenneth L. Bickel

UNITED STATES DEPARTMENT OF THE INTERIOR

United States. Bureau of Mines.

Information Circular 8832

Automatic Fire Protection Systems for Surface Mining Equipment

By William H. Pomroy and Kenneth L. Bickel

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES
Lindsay D. Norman, Director

This publication has been cataloged as follows:

Pomroy, William H
Automatic fire protection systems for surface mining equipment.

(Information circular - Bureau of Mines ; 8832)
Bibliography: p. 36-38.
Supt. of Docs. no.: I 28.27:8832.

1. Strip mining—Fires and fire prevention I. Bickel, Kenneth L., joint author. II. Title. III. Series: United States. Bureau of Mines. Information circular ; 8832.

TN295.U4 [TN315] 622s [622.8] 80-607030

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

AUTOMATIC FIRE PROTECTION SYSTEMS FOR SURFACE MINING EQUIPMENT

by

William H. Pomroy [1] and Kenneth L. Bickel [1]

ABSTRACT

Fire on surface mining equipment is a serious hazard to life and property. The Bureau of Mines, through a program of contract and in-house research, has developed and in-mine demonstrated reasonably priced, reliable automatic fire protection systems to deal with this problem. This report reviews the development and subsequent testing of systems for haulage trucks, front end loaders, coal augers, dozers, drills, and shovels. A variety of fire sensors, extinguishing agents, and control systems are discussed in the context of mine equipment designs and operating environments.

INTRODUCTION

Fire on surface mining equipment is a serious hazard to life and property. The large size of this equipment magnifies the problem by increasing the potential for fires, obstructing the operators' view of fire hazards, and restricting their egress from the vehicles. Serious personal injuries frequently result, and property damages in excess of $100,000 per fire are not uncommon (fig. 1). In addition, production drops until the damaged equipment is repaired or new equipment is delivered.

To avoid these problems, regulatory agencies and insurance companies require fire protection hardware on these machines. Usually, a portable extinguisher is mounted in or near the operator's cab, with perhaps another mounted elsewhere on the vehicle. With the increasing size of vehicles, however, portable extinguishers do not provide adequate protection.

Many manufacturers offer manually activated, fixed fire-suppression systems to supplement portable extinguishers. These systems consist of one or more containers of fire suppressant (usually a dry chemical) connected by a fixed plumbing network to nozzles directed at specific, predetermined fire hazard areas (fig. 2). To use the system, the operator must detect the fire and activate a cab-mounted electric or pneumatic releasing device, but the large size of this equipment makes it difficult for an operator to see the

[1]Mining engineer, Bureau of Mines, Twin Cities Research Center, Twin Cities, Minn.

FIGURE 1. - Typical mine vehicle fire.

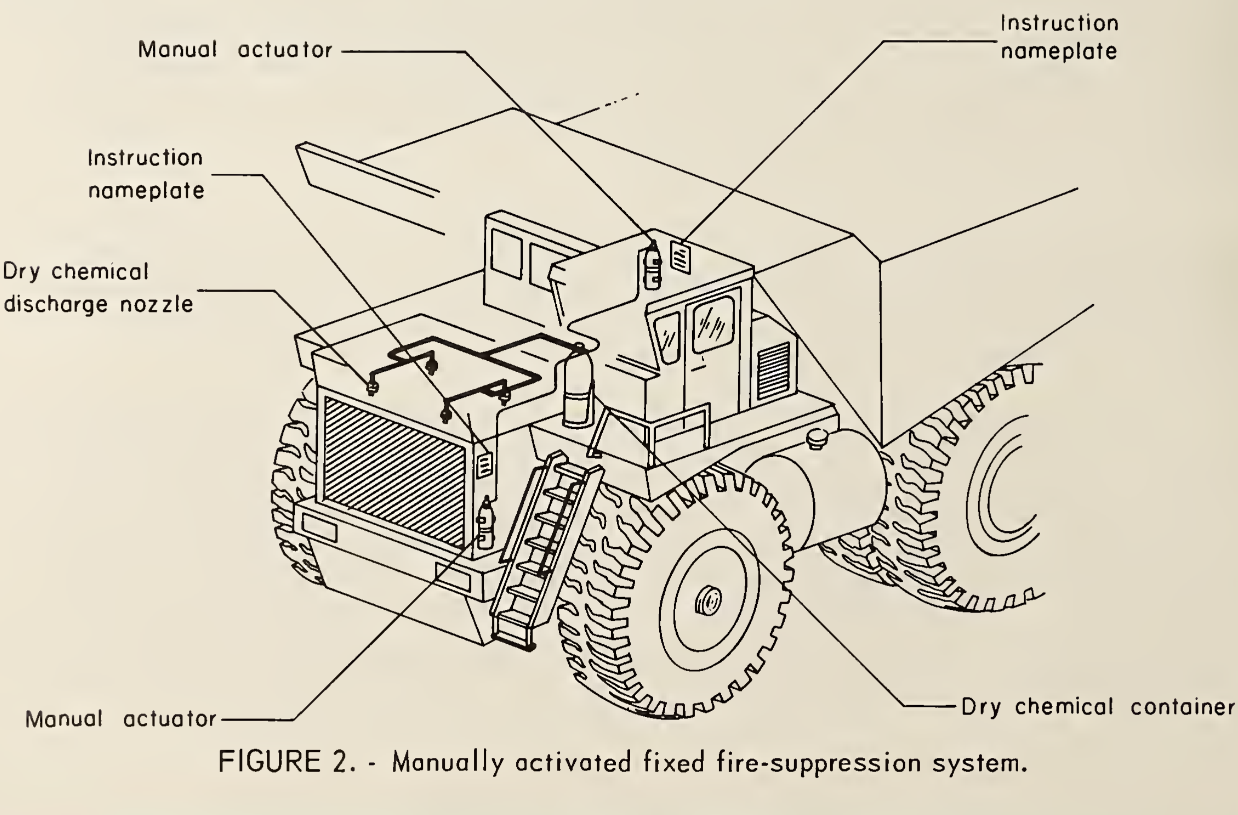

FIGURE 2. - Manually activated fixed fire-suppression system.

fire until it has grown out of control. Operators often panic, fail to activate the system, and in their haste to escape, jump from the cab to the ground, sustaining serious injury.

To avoid the problems of manually activated systems, the Bureau of Mines developed automatic fire sensing and suppression systems for mining equipment. This program sought to demonstrate, through in-mine tests, that rugged, reliable, cost-effective automatic systems for mine equipment could be developed from existing fire protection technology. Whenever possible, off-the-shelf components were used. Numerous combinations of components were tested to demonstrate the flexibility of available design options. Although each system was designed for a specific application, it should be noted that--

(1) Any given fire system design could be well suited to protecting many different types of vehicles, and

(2) Several alternative fire system designs could be used effectively on one vehicle.

Haulage trucks were selected for initial development because their fire hazards are typical of most mine equipment and because they compose the largest class of mine vehicles. Using hardware developed for military and petrochemical applications, a system was installed and tested on a 100-ton haulage truck at the Cyprus Pima copper mine near Tucson, Ariz.(9).[2] This first generation prototype system, which protected the truck's engine and dynamic brake grids, used optical and thermal fire sensors to trigger stored-pressure dry chemical extinguishers (fig. 3). Automatic controls with manual override were provided. A second-generation prototype system was installed at the Erie taconite mine near Hoyt Lakes, Minn., for cold weather testing. These tests culminated in actual fire tests (fig. 4) and demonstrated that such automatic systems are feasible. The successful demonstration of this prototype hardware on haulage trucks led to the development of improved systems that were tailored to the specific fire protection needs of many types of mining equipment.

This Bureau of Mines report discusses the development of these systems and illustrates their use in mines. It is divided into seven sections, covering haulage trucks, coal augers, dozers, front end loaders, blasthole drills, diesel hydraulic shovels, and electric mining shovels. Each section describes the factors that were considered in the design of the system, development of hardware components, and subsequent in-mine, on-vehicle tests.

DESCRIPTION OF PROTOTYPE SYSTEMS

Haulage Trucks

Typical fire hazard areas on mine haulage vehicles include the engine, transmission, fuel tanks, and in some cases, dynamic brake grids. Parking brake and dashboard electrical fires are common, but usually are small enough

---

[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

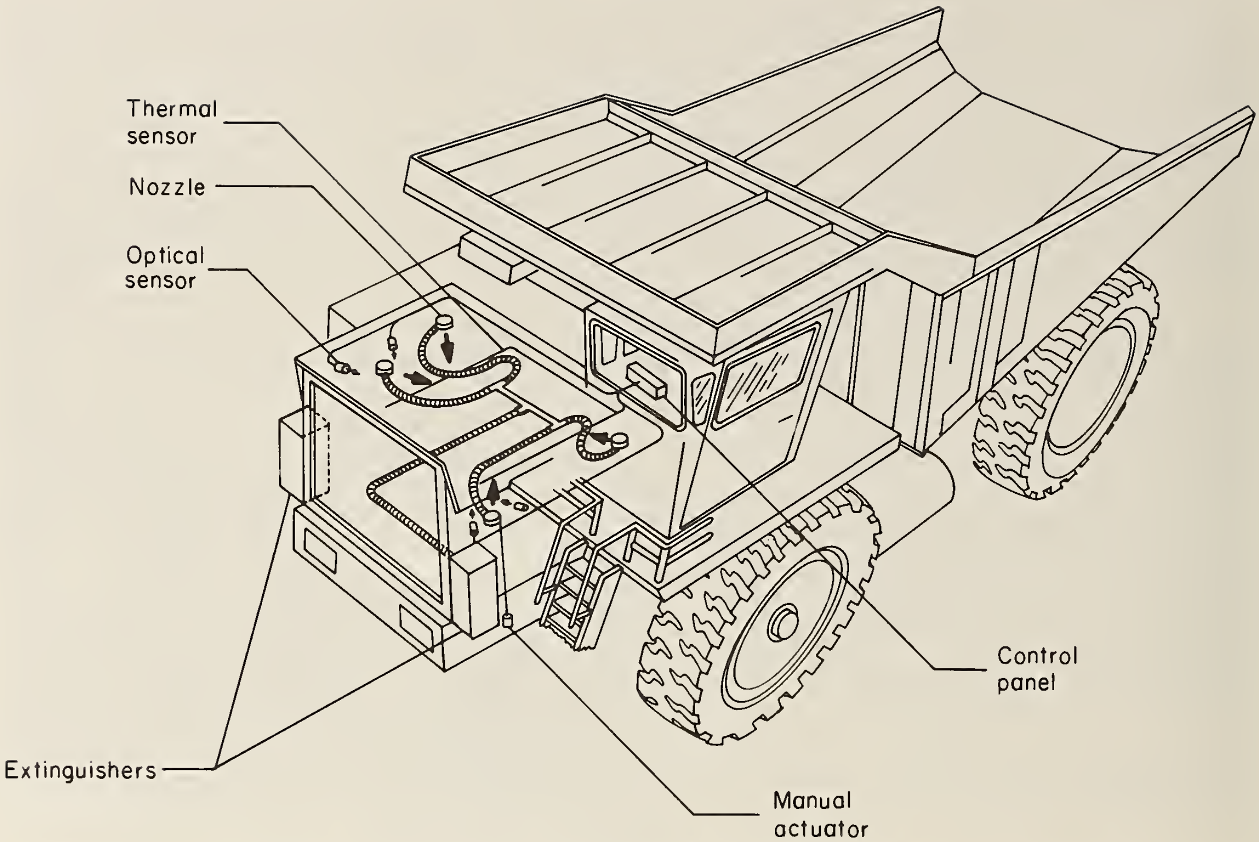

FIGURE 3. - First-generation prototype automatic fire protection system for haulage trucks.

FIGURE 4. - Fire tests of first-generation fire protection system for haulage trucks.

to be put out with a portable extinguisher. The worst fires generally are caused when ruptured high-pressure hoses spray combustible fluids onto hot surfaces. The resulting fast-growing class B fires are difficult to extinguish and significantly impede safe operator egress, especially in larger trucks, where the cab-to-ground distance can be as far as 12 feet.

Optical and Thermal Sensing, Stored-Pressure Suppressant

The long-term ruggedness and reliability of the first-generation automatic vehicle fire protection system developed under two Bureau of Mines contracts (3-6) were evaluated by installing a system of both optical and thermal fire-sensing and stored-pressure dry chemical suppression on a 120-ton Wabco[3] bottom-dump coal hauler in the Jim Bridger mine near Rock Springs, Wyo. (18).

Dual fire sensing was selected to provide both rapid response and high reliability. Optical sensors trade off rapid detection for low reliability, while thermal sensors trade off high reliability for slow detection. Both sensor types were used to combine the positive features of each. Four near-infrared optical flame detectors were mounted above and away from the mud-slinging tires and under the engine hood and A-frame to observe the exhaust and turbocharger areas. A thermistor-core detection cable was used with the optical sensors. The 16-foot-long, steel-sheathed cable, 5/64 inch in diameter, contained two electrical conductors separated by a semiconductor material whose electrical resistance varied sharply with the temperature. The resistance between the two conductors indicated temperature. (This extremely rugged sensor is common on commercial aircraft and marine vessels.) On the mine equipment, the heat-sensing cable was arranged in a U-shaped looped circuit, with legs extending forward over the exhaust manifolds, then routed under the A-frame at the rear of the engine. An ambient temperature probe was installed near the truck ladder to automatically adjust the alarm setting of the thermal sensor, depending on the ambient temperature. The control panel assembly consisted of an ON-OFF-TEST/RESET switch, audible and visual fire warning indicators, and a manual override discharge button. The manual override discharge button initiated discharge of extinguishant even when the control panel power switch was off. Current was supplied directly by the vehicle's battery. If an optical sensor detected a fire, a yellow FAULT/FLAME warning light on the control panel illuminated and the audible alarm sounded. There was no automatic discharge of the dry-chemical powder if fires were sensed only by the optical sensors. If the thermal device alone sensed a fire, the red FIRE warning illuminated and an alarm sounded. The system automatically discharged the agent after a 10-second delay, during which time the driver could stop, turn off the engine, and test the system for malfunctions. Moving the control panel switch to TEST/RESET during the 10-second delay reset the discharge delay to provide an additional 10 seconds after the control panel switch was released from the test position.

---

[3]Reference to specific trade names is made for information only and does not constitute endorsement by the Bureau of Mines.

When optical and thermal sensors detected a fire simultaneously, the dry chemical was immediately discharged to suppress the probable flash fire situation. Immediate discharge also could be initiated manually by striking the discharge button.

A remote system discharge switch, located at the base of the ladder, permitted manual actuation of the system without any fire signals, regardless of the position of the control panel switch or of the truck's master switch.

The integrity of the control circuit was monitored constantly, and the operator was alerted to any electrical malfunction by the yellow light and pulsing horn.

Multipurpose dry chemical (monoammonium phosphate) was selected as the fire suppressant agent. This agent is effective in suppressing A, B, and C class fires (ordinary combustibles, flammable and combustible fluids, and electrical), but is particularly effective on class B fires, which are the most common class of fires on haulage trucks. The agent was contained in two 25-pound-capacity cylinders, pressurized to 500 pounds per square inch (psi) with dry nitrogen. A switch monitored nitrogen pressure and if the pressure fell below 450 psi, a yellow fault light on the control panel illuminated. The cylinders were prepressurized to avoid caking of the dry chemical. Each cylinder was fitted with a solenoid valve to discharge the suppressant. The cylinders were housed in two protective enclosures mounted on the right front corner of the truck's operator deck. A manifold connected to the outlet port

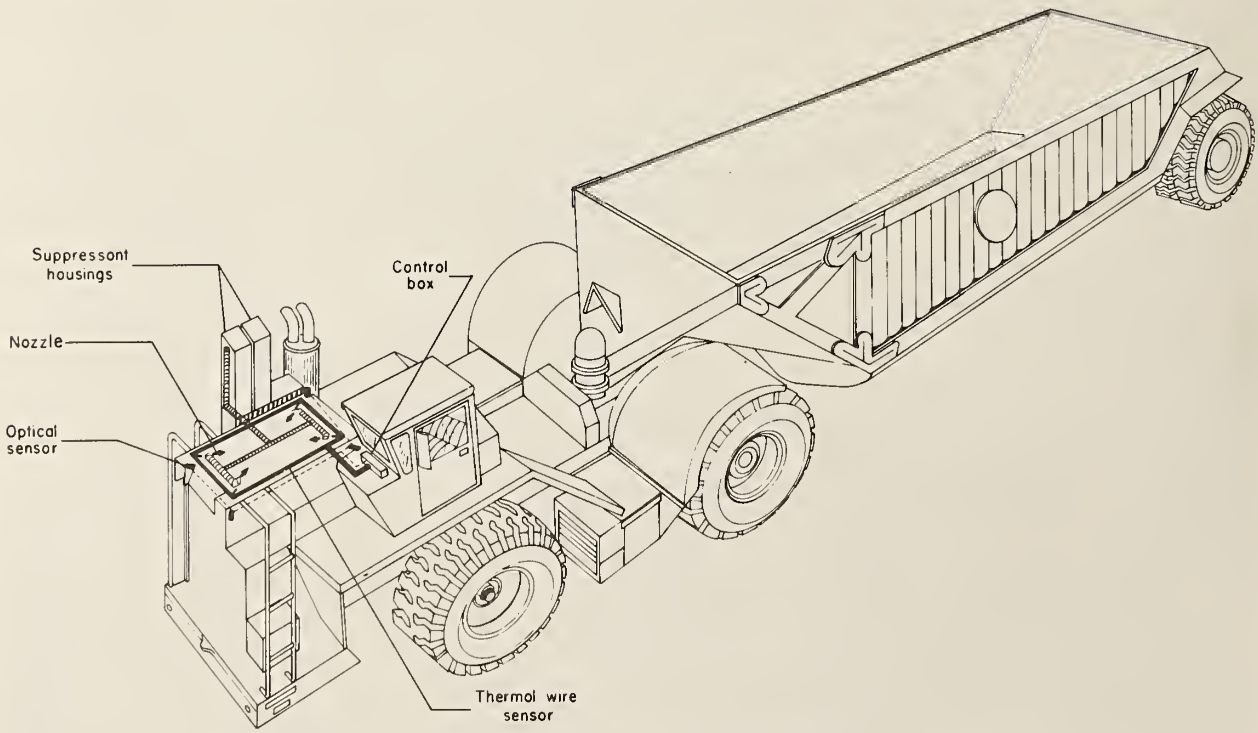

FIGURE 5. - Automatic fire protection system for coal haulers.

of each cylinder divided the flow of dry chemical through four flexible, steel-braid-reinforced hydraulic hoses to fixed nozzles. Four nozzles from one cylinder each with a 180° fan-shaped discharge pattern, were directed so that the flow of extinguishing agent was divided half above and half below the exhaust manifolds in the engine area. Two of the four nozzles from the second cylinder had the same fan pattern and were directed to obtain equal flow over the transmission. The remaining two units were 360° cone-shaped nozzles, one pointed to the oil reservoir and one to the diesel fuel tank saddle mounted to the rear frame. A schematic of the system design is shown in figure 5.

The system was installed on a bottom-dump coal hauler in January 1977 for a 10-month endurance test. After that time, the system was fire-tested by applying a torch to the thermal wire sensor. An optical sensor detected the presence of flame immediately and in spite of an ambient temperature of 40° F and cross winds through the engine area exceeding 40 mph, the thermal wire responded to the heat in approximately 30 seconds. The system then discharged and distributed sufficient powder to all protected areas of the machine (fig. 6).

However, during this 10-month period, several weaknesses were identified in the system design. The system was susceptible to false alarms during periods of low vehicle-battery voltage. Although the suppressant was not discharged, the fire and fault lights illuminated and the alarm sounded. In addition, inductive voltage or electrical transients occasionally cycled the

FIGURE 6. - Test of coal hauler fire protection system.

system through the test sequence. Also, during the first 2 months of the endurance test, pressure was lost from the suppressant cylinders. Starting the third month of the test, the originally installed neoprene seals in the solenoid valve were replaced with specially manufactured cast urethane seals, which corrected this problem. The optical sensors proved unreliable because of dirt buildup on the lenses. The optical sensor that detected the flame during the fire tests of the system responded only because its lens had been wiped clean immediately prior to the test. During previous in-mine tests of this sensor, false alarms caused by red sunsets, welding, etc., were a problem. However, no false alarms attributable to the optical sensors were encountered during this test program, probably because of the rapid buildup of dirt.

Optical and Thermal Sensing, Cartridge-Activated Suppressant

The same fire protection system design was tested on a 170-ton Wabco ore haulage truck at the Cyprus Pima mine near Tucson, Ariz. This second system was identical to the one tested on the coal hauler at the Jim Bridger mine.

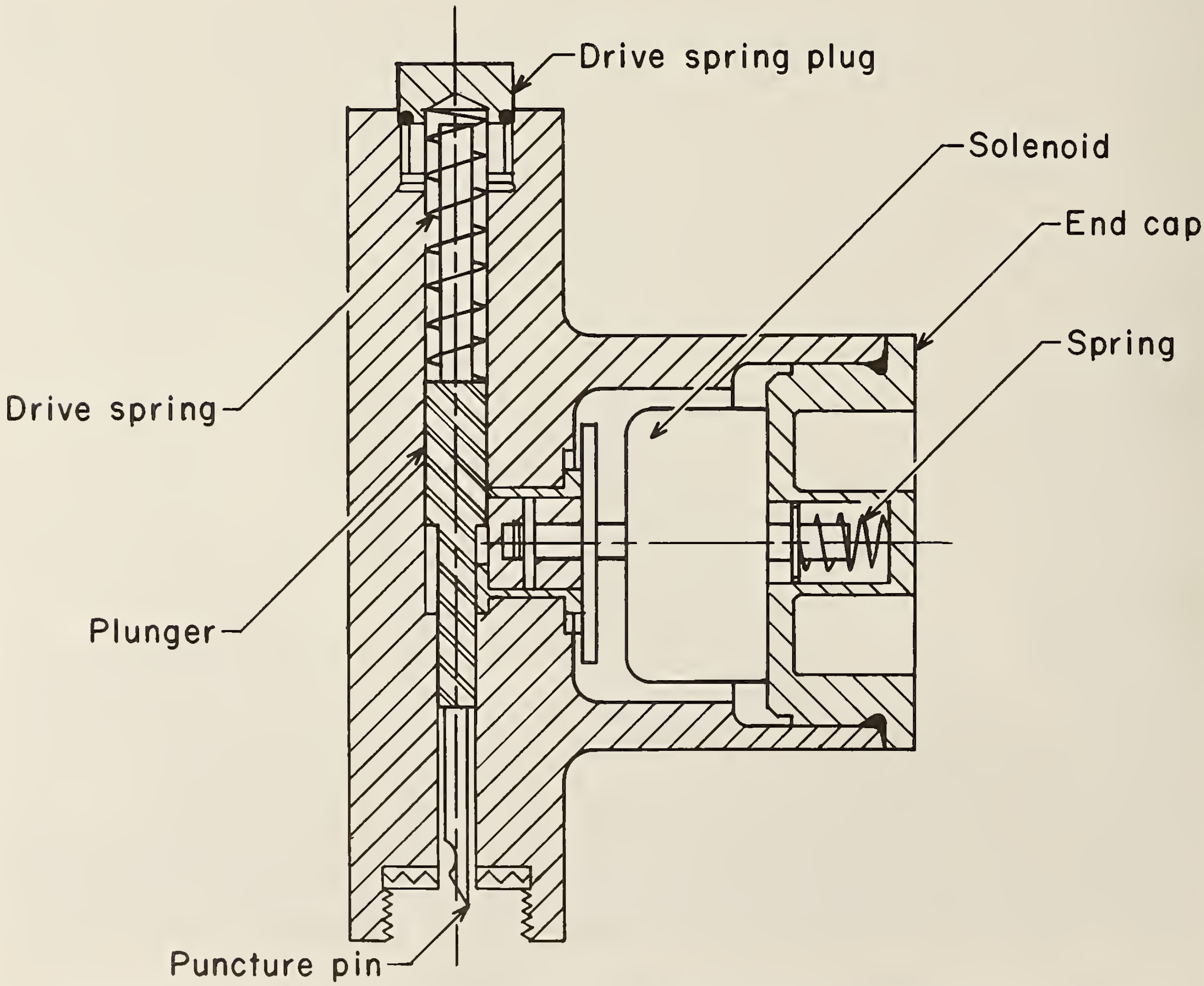

FIGURE 7. - Solenoid-activated spring cartridge-type actuator for fire protection systems.

The installation was made under a service contract in January 1977. After 7 months of operation on the truck, the system was converted from stored-pressure to cartridge-activated extinguishers because of recurring pressure losses from the original units, and to test a specially designed cartridge-puncturing device. Manually activated, fixed fire-suppression systems are common on this type of equipment. Such a cartridge-puncturing device would allow mine operators to convert their manual systems to automatic operation. The cartridge-activated suppression system consisted of the solenoid-operated, gas-cartridge-puncturing device (fig. 7), and two nonpressurized 25-lb dry chemical extinguishers. When supplied with an electric current, the solenoid actuated, releasing a spring-loaded puncture pin. The puncture pin pierced the brass seal of a high-pressure nitrogen cartridge. The nitrogen was carried to the extinguishers through a short length of hydraulic hose. The gas pressurized and expelled the dry chemical from the extinguishers through a fixed network of hoses to eight discharge nozzles. A schematic drawing depicting the layout of the system is shown in figure 8. (As noted previously, the problem of pressure loss was later corrected on the coal hauler with the use of improved urethane valve seats.) Following this conversion, the system underwent continuing endurance tests until the test vehicle was removed from production service in November 1977.

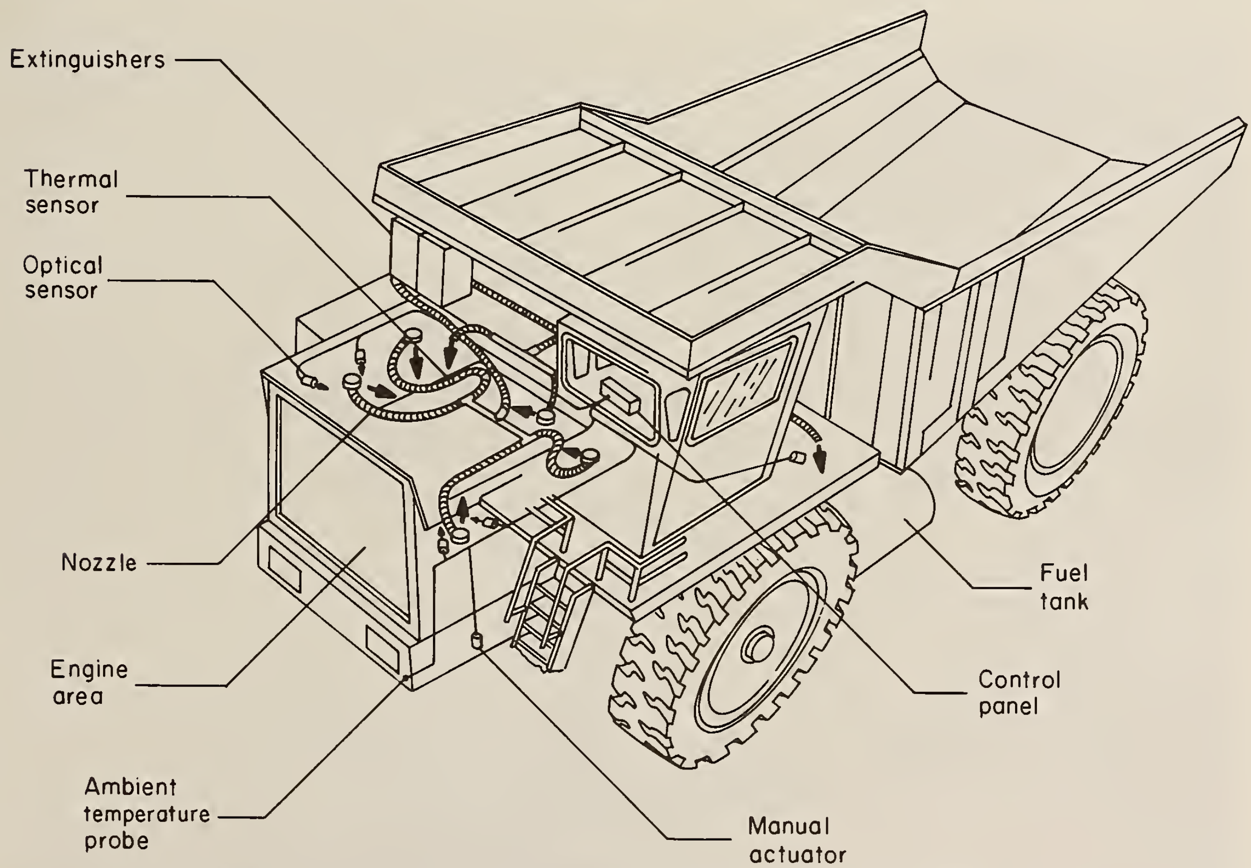

FIGURE 8. - Automatic fire protection system for mine haulage vehicles.

Field performance of this system closely paralleled that of the one on the coal hauler. Pressure loss from the extinguishers and dirt buildup on the optical sensors were the principal operational problems. However, unlike the coal hauler system, electrical transients did not interfere with system performance. The system was discharged once by a mine mechanic who mistook the ground level remote manual discharge switch for a truck ladder light switch.

Thermal Sensing, Cartridge-Activated Suppression

Due to problems of pressure loss from prepressurized extinguishers and dirt on optical sensors (as described previously), a third system was developed which used cartridge-activated extinguishers and thermal wire sensing. This system, which was specifically designed to retrofit automatic actuation to an existing manual system, was installed on an ash haulage truck at the Jim Bridger mine in February 1977 (18). Thermistor-core wire was again used as the fire-sensing element and the suppressant was supplied by cartridge-activated extinguishers. The control system was similar to those described previously. The heat-sensing wire, control box, and suppressant nozzles were mounted as they were on the coal hauler. The actuation device was mounted under the left front fender. The ground level manual actuator was mounted near the base of the ladder.

FIGURE 9. - Test of automatic fire protection system on an ash hauler.

The system was fire tested in November 1977 by applying a torch to the thermal wire sensor. The system sensed the fire within about 60 seconds and automatically discharged the fire suppressant agent (fig. 9). Good dry chemical coverage was obtained despite 40 mph cross winds through the engine area.

During the 9-month endurance test period, the control system was found to be sensitive to low voltage. The problem occurred only when the engine was off and the lights were on. Low voltage caused the fire alarm system lights to illuminate dimly and the system to sound a weak audible alarm. Several discharges of the system occurred during the test program as a result of manual activation by mine personnel unfamiliar with the system.

Thermal Sensing, Warning-Only System

As a low-cost alternative to an automatic system, and to provide more manual control over the fire protection system, a warning-only system was developed by the Bureau to be used in conjunction with a manually activated fixed fire-suppression system. This system gives the vehicle operator early warning of a fire condition, but it does not automatically activate a fire-suppression system. Thus, if vehicle operators are not present or should they panic during fire emergencies and fail to activate the fire protection system, fire suppressant will not be discharged. This warning-only system consists of a thermistor-core sensing cable connected to a cab-mounted control box. The control box is fitted with visual and audible fire alarms and a system circuit

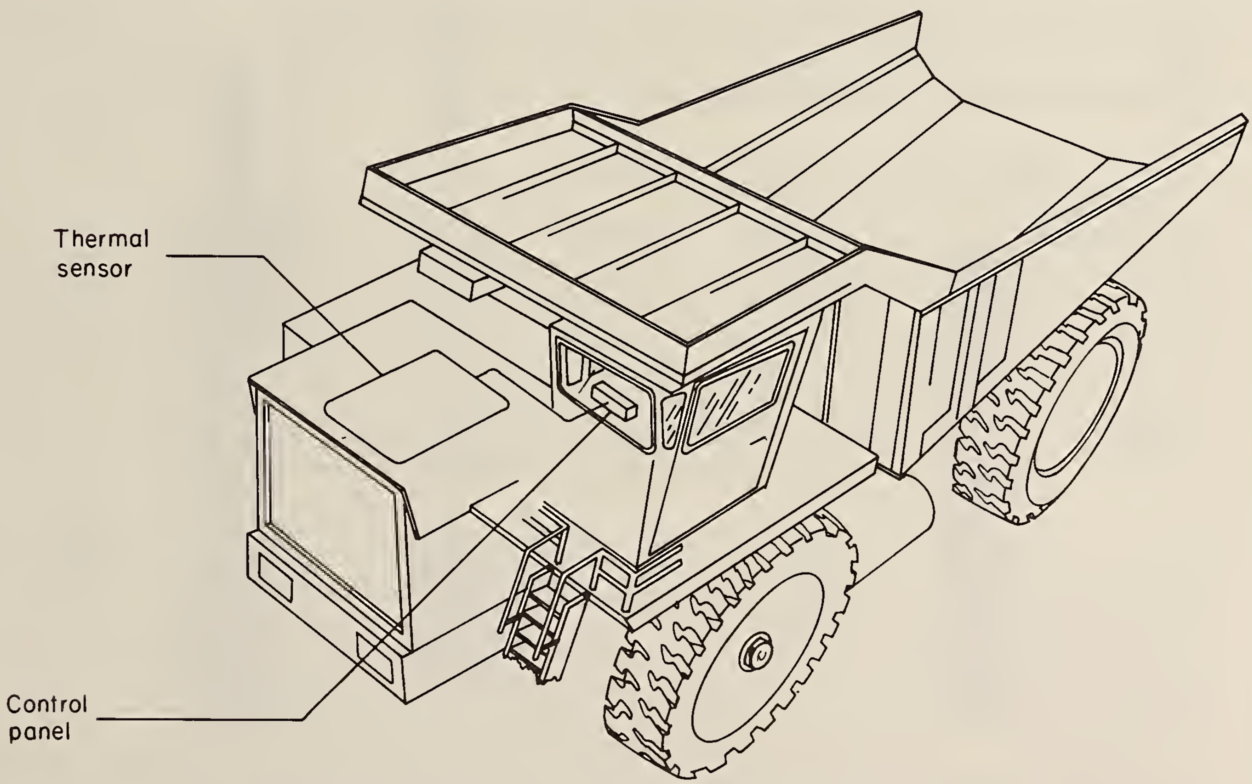

FIGURE 10. - Fire warning system for mine haulage trucks.

integrity test switch. This system was installed on a 100-ton Unit Rig haulage truck at the Reserve taconite mine near Babbitt, Minn., in May 1977. The control box was installed directly onto the vehicle dashboard to the right of the driver, with the manual fire protection system activator bolted to the top of the box. The sensor wire was looped through the truck's engine area (fig. 10) from mounting clips attached to the vehicle frame. The system was functionally tested following the installation and at 4-month intervals thereafter. It functioned without failure during an 18-month endurance trial period.

Fusible Plastic Tube Sensing, Cartridge-Actuated Suppressant

A totally nonelectric automatic fire sensing and suppression system was tested on two mine haulage trucks via a memorandum of agreement between its manufacturer, the Ansul Co. of Marinette, Wisc., and the Bureau from 1975 to 1977. To avoid dependence of the system on complex and sometimes unreliable vehicle electrical systems, the firm developed a fusible plastic tube sensing system that triggers cartridge-actuated dry chemical extinguishers by a pneumatic signal. The fire detector consists of three elements: detection tubing, a pressure make-up device (PMD), and a detection actuation device (DAD) (fig. 11). The ¼-inch-outside-diameter detection tubing, made of nylon approved by the Department of Transportation for air brakes on over-the-road

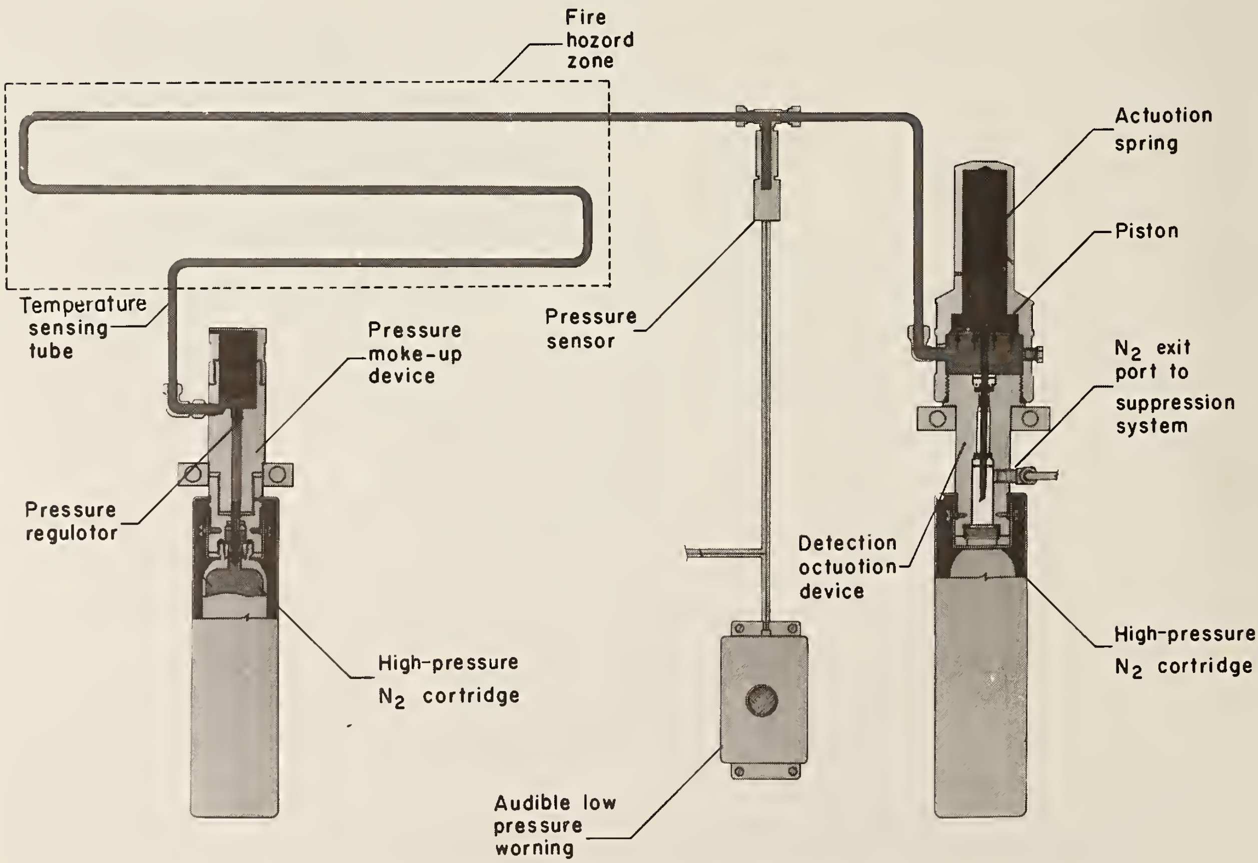

FIGURE 11. - Fusible plastic tube fire-sensing system.

trucks, is strung between the PMD and DAD so that it passes through all fire hazard areas to be protected. A high-pressure (1,800-psi) nitrogen gas cartridge is then attached to the PMD, pressurizing the detection tubing through a regulator to about 80 psi. As the detection tubing loses pressure through slow leaks at connections (which are almost impossible to avoid), the PMD automatically "bleeds" in nitrogen from the high-pressure cartridge to maintain the 80 psi in the tubing. This pressure acts on a piston and puncture pin assembly in the DAD to compress an actuation spring. When the heat from a fire softens the detection tubing (at about 355° F), the internal gas pressure causes the tube to burst. The rapid release of gas allows the actuation spring force to overcome the nitrogen pressure on the piston in the DAD, causing the puncture pin assembly to pierce the brass seal of a second high-pressure nitrogen cartridge. This gas operates a cartridge-actuated fixed dry chemical suppression system. The system may also be manually activated.

Both hot weather and cold weather in-mine tests of the system were performed to determine the rate of pressure loss from the PMD cartridge. One system was installed on a 150-ton ore haulage truck at the Pinto Valley copper mine in Arizona. A second system was installed at the Minntac taconite mine in northern Minnesota. Gas pressure inside the PMD of each system was measured daily with a pressure gage on the high-pressure side of the regulator. Readings were taken on the Pinto Valley system for 17 months and the Minntac system for 2 months. Pressure loss was approximately 2.5 psi per day at Pinto Valley, indicating that a new PMD cartridge would be required after about 24 months of use. No pressure loss was observed on the Minntac truck.

All of these haulage truck automatic fire sensing and suppression systems are now commercially available for from $850 to $5,000, depending on design and capability.

Coal Augers

Primary fire hazard areas on coal augers include the auger engine compartment and (on certain machines) the auxiliary engine used to position auger flights. Typical combustible fluids involved are hydraulic oil, lubricating oils and greases, and diesel fuel. Also present are electrical controls and ordinary combustibles such as electrical insulation, hoses, accumulations of coal dust and other debris. Because people must be near both fire hazard areas to operate the machine and because fast growing class B fires in these areas can be expected, a reliable automatic fire suppression system is essential.

In 1974, a research contract was issued to develop and in-mine test such a system. The system featured spot-type, fixed-temperature thermal bimetallic sensors in the two engine areas and cartridge-activated multipurpose dry chemical suppression (fig. 12). When the sensors were exposed to a temperature of 300° F, an electrical circuit was completed which energized a solenoid-operated valve. This valve released high pressure CO_2 gas, which made a puncture pin pierce a brass seal on a second CO_2 gas cartridge (fig. 13). This gas fluidized and pressurized the dry chemical in the extinguisher shells. The pressurized dry chemical was piped through thin-walled steel tubing into

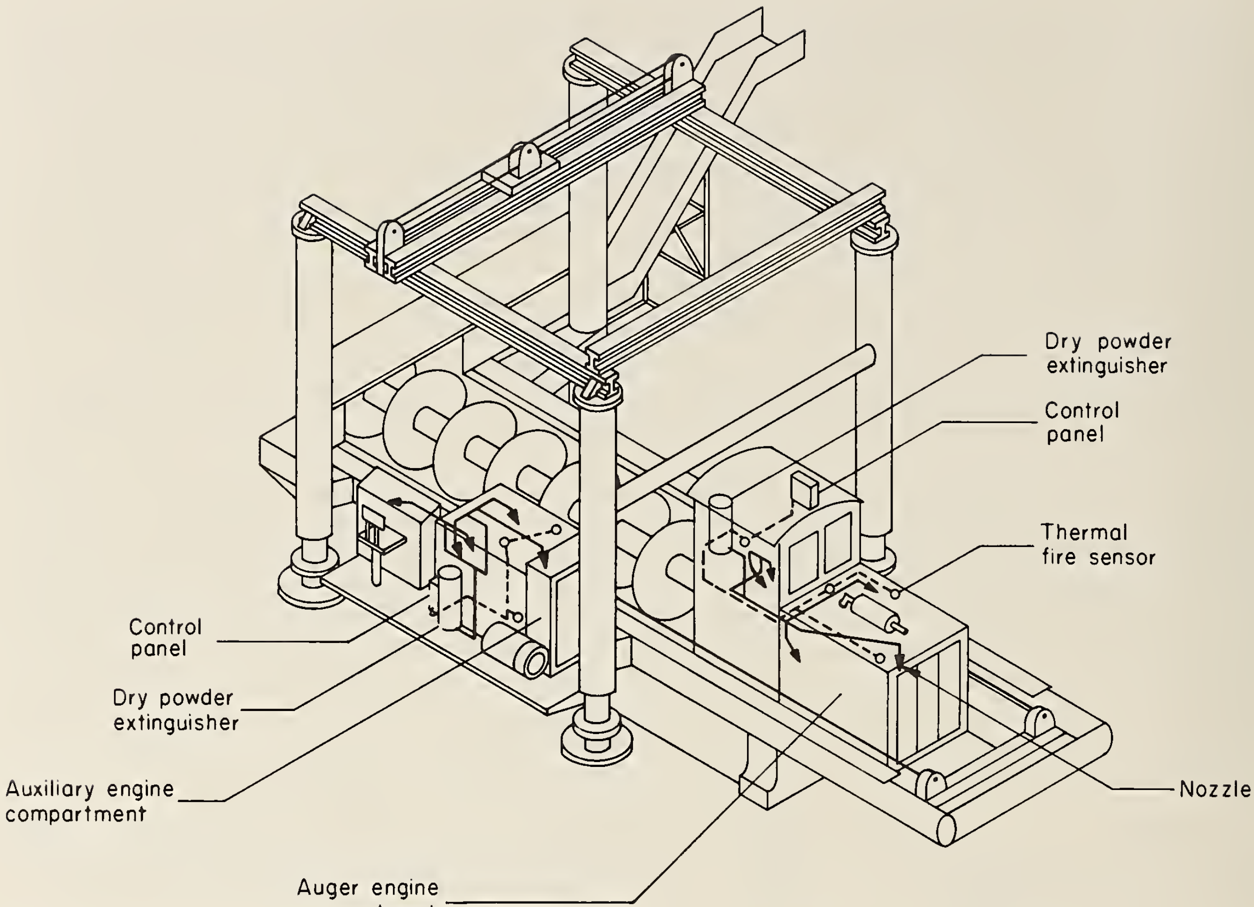

FIGURE 12. - Automatic fire protection system for coal augers.

both engine and transmission areas and also around the hydraulic control panels. Semidirectional cone spray nozzles totally flooded these areas while directing powder away from the operators.

The system was installed on a Compton coal auger at the Cedar Coal Co.'s Chelyan, W. Va., mine in 1975. During an 8-month endurance test period, two discharge tests were performed (fig. 14). In each case, discharge was successful. Even with the auxiliary engine running at full throttle, powder was deposited in good depth throughout the engine-transmission compartments and all the hydraulic control areas. The machine operators agreed that the discharge of the system did not interfere with safe personnel egress.

During this test period, the actuator gas cartridge lost pressure. This loss was attributed to "puff-leakage" through the solenoid valve caused by shock and vibration. This pressure loss would not have resulted in accidental discharge of the system or impaired manual discharge capability; however, over a long time period, automatic system discharge capability may have been impaired. Subsequent redesign of the actuator corrected this deficiency. Systems based on this improved design are commercially available at from $1,000 to $3,000.

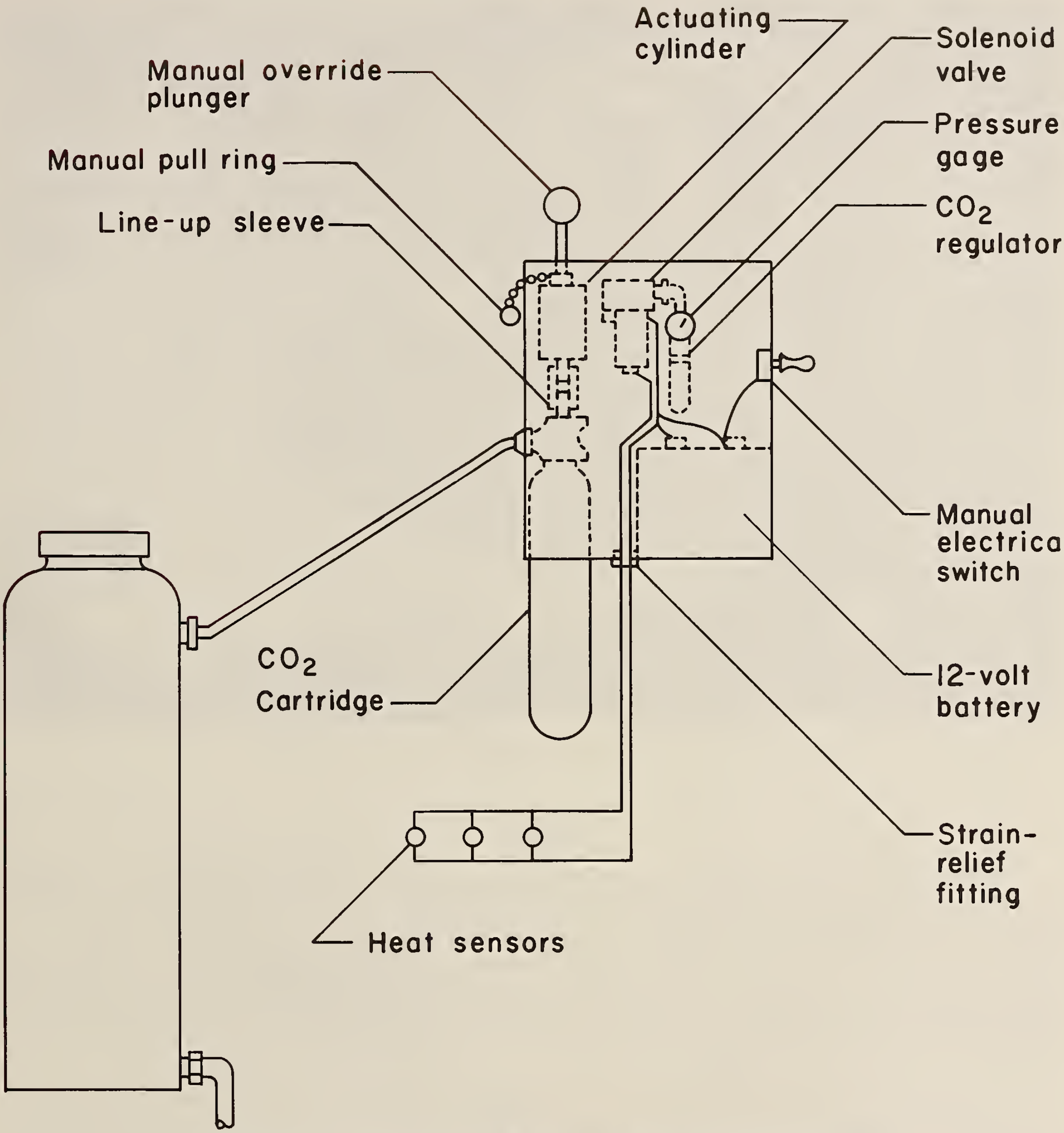

FIGURE 13. - Actuator for the coal auger fire protection system.

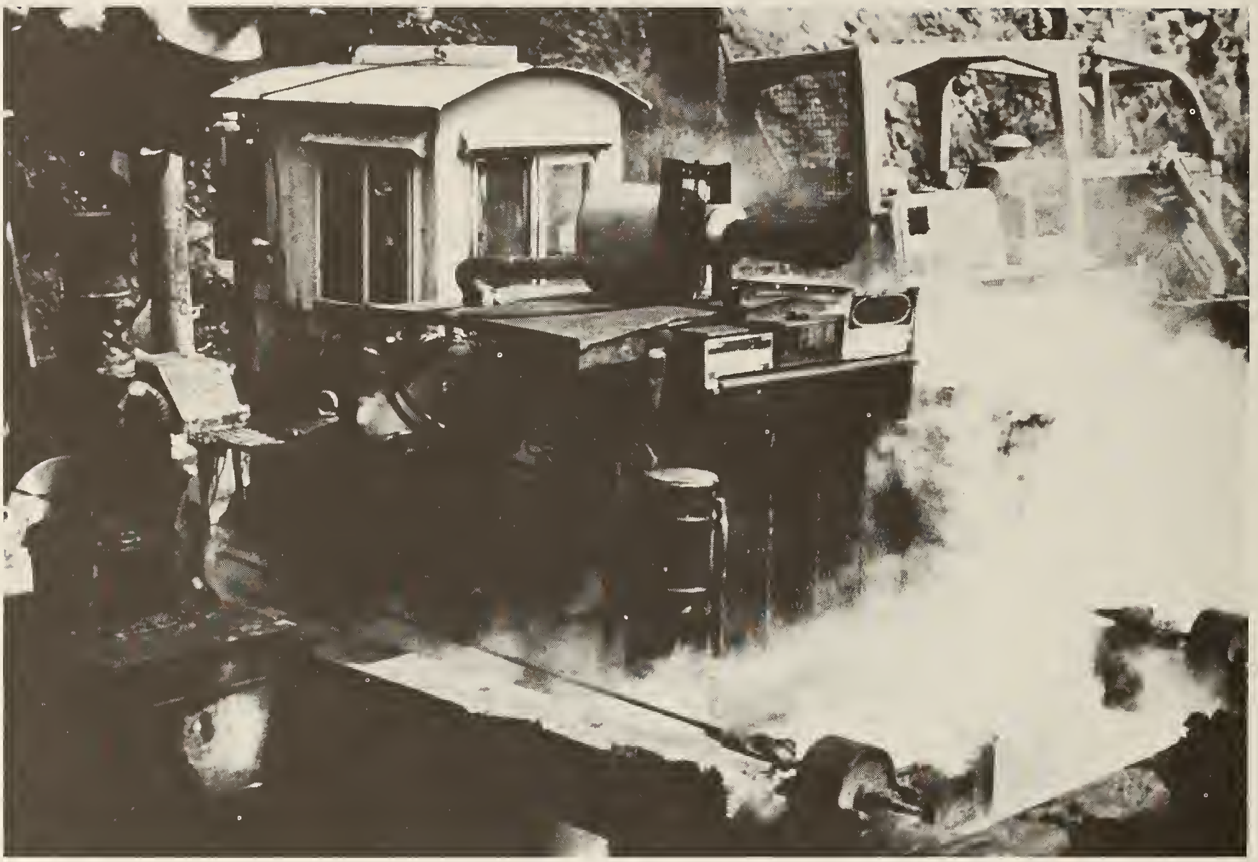

FIGURE 14. - Test of coal auger fire protection system.

Dozers

The primary fire hazard areas on a large dozer are the engine and transmission, and hydraulic pump areas. Failure of any of the numerous lines or fittings carrying high-pressure, high-temperature combustible fluids near ignition sources such as hot manifolds often results in a flash fire. Because egress from large dozers is difficult, such flash fires are a significant safety problem. In 1975, a research contract was awarded for development and testing of an automatic fire suppression system for mining dozers (12).

The resulting system utilizes inexpensive spot-type fixed-temperature thermal fire sensors and a specially designed, squib activated cartridge type multipurpose dry-chemical extinguishing system (fig. 15). When any one of the sensors is exposed to a temperature above 300° F, an electrical circuit is closed, firing the squib. The expanding gases from this squib charge cause a puncture pin to pierce the brass seal on a high-pressure nitrogen gas cartridge (fig. 16). The release of the nitrogen gas fluidizes and discharges the dry chemical from the extinguisher shell. The dry chemical is piped to preselected hazard areas. The system also may be manually discharged.

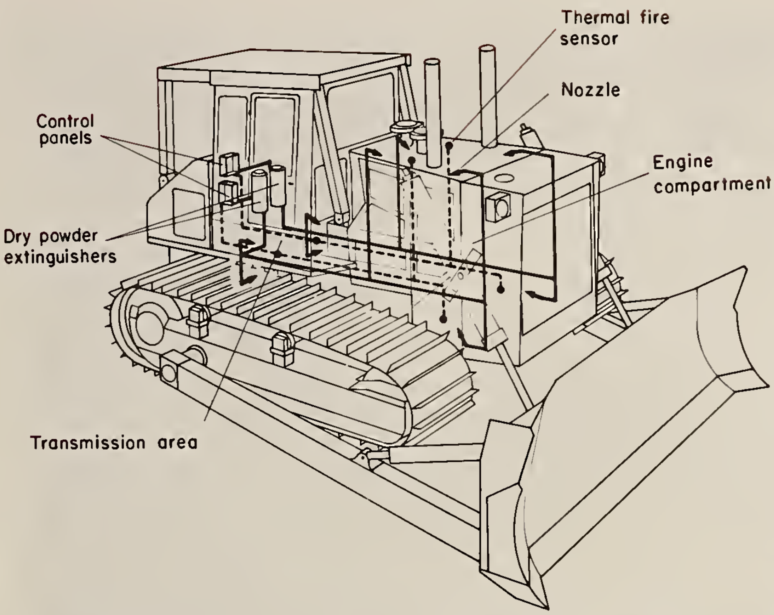

FIGURE 15. - Automatic fire protection system for mining dozers.

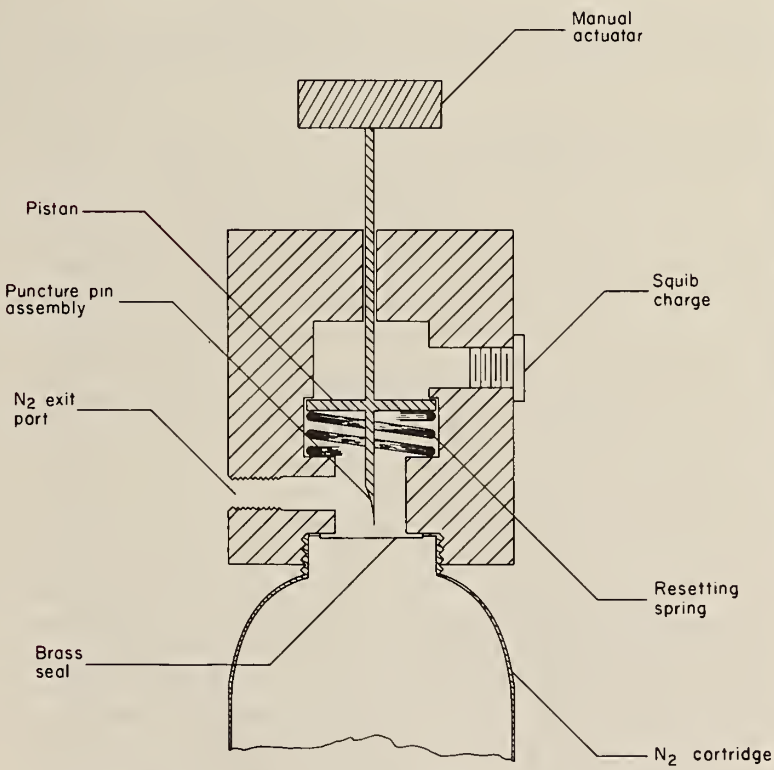

FIGURE 16. - Explosive squib-type actuator for automatic fire suppression systems.

In November 1975, the system was installed on a Lemmons and Company Fiat Allis HD 41 Tractor in Boonville, Ind. The system consisted of two 30-lb dry chemical extinguishers, ten cone spray nozzles, six 300° F heat sensors, a control box, and the necessary tubing and high temperature wiring. Installation required approximately 30 manhours.

After installation and a final checkout, the system was successfully test fired by heating one of the sensors with a small butane torch (fig. 17). Powder deposition was as anticipated with good coverage on the engine converter, blower, fuel pump, starter, filters, pumps, hoses, transmission, and belly pan. The test was conducted with the engine running. Although some powder was blown out of the engine compartment by the engine fan, this had been considered in the system design, and sufficient powder remained for good coverage in all desired areas.

In February 1977, after 4 months of field operation, a final firing test was performed. Again a torch heated one sensor and actuation was successful. Subsequent examination of the interior showed deposits of power ranging from 1/32 to 1/4 inch over all protected areas.

During the test program, no operational problems with

FIGURE 17. - Test of mining dozer automatic fire protection system.

the hardware were observed. This system and others with similar capabilities are commercially available from $850 to $4,000.

Front End Loaders

Fire protection on large front end loaders is especially important, both because of the vehicle's size and because of the relative location of the cab, engine, articulation area, and egress routes. The cab on most large loaders is at least 10 feet from ground level. If the operator leaps to the ground, the likelihood of serious injury is quite high. Moreover, normal egress routes lead past the engine and articulation areas which, owing to the presence of both fuels and ignition sources, are primary fire hazard zones. To help improve safety on these machines, two front end loader automatic fire protection systems were developed and in-mine tested.

Thermal Sensing, Cartridge Activated Suppressant

In June 1976, a research contract was awarded for development and testing of an automatic fire protection system for large front end loaders. The contractor fabricated the hardware for a Clark 675 loader, but the design is flexible so the system can be used on other machines as well. The Clark 675 was selected for tests because of its size (24-yard capacity, overall length of 50 feet, width of 17 feet, operator cab 12 feet above the ground). Four extinguisher shells, each containing approximately 30 lb of multipurpose dry chemical, are required to provide adequate suppressant coverage in all hazard areas (fig. 18). The dry chemical is piped to the hazard areas. Cone-shaped spray nozzles with hinged covers are used for agent dispersal. These nozzles

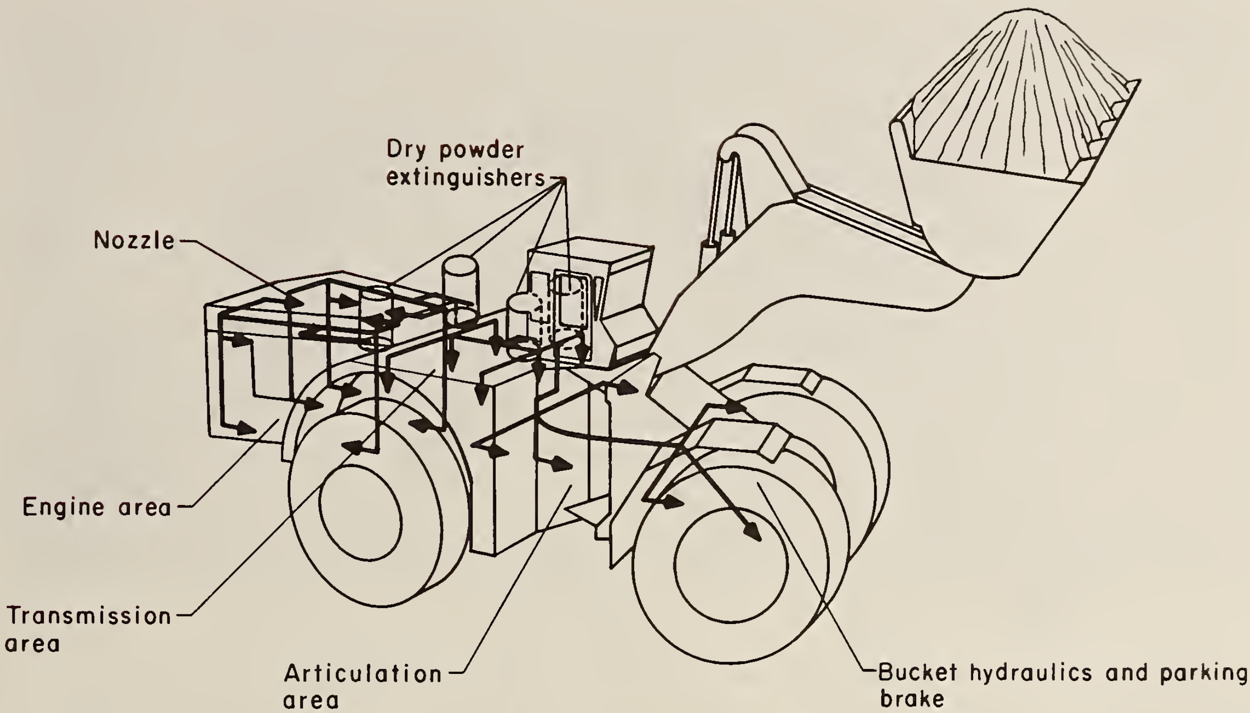

FIGURE 18. - Automatic fire protection system for large front end loaders.

are relatively clog-free and disperse the agent in a wide pattern which not only totally floods the interior, but also casts powder behind filters and other components not directly in line with the nozzle.

Inexpensive spot-type fixed temperature thermal fire sensors are used. These sensors close an electrical circuit when exposed to a temperature above 300° F. In the event of fire, current is supplied from a 6-volt battery (independent of the vehicle's electrical system) to a squib. The squib selected for this system is the same one used on the dozer. It is a spin-off from the space program and is extremely reliable. It has a maximum safe non-fire current of 1 ampere and a minimum sure fire current of 2 amperes. It will not fire from two-way radio or blasting current fields. The expanding gases from the squib charge causes a puncture pin to pierce the brass seal on a high-pressure nitrogen gas cartridge (fig. 16). The gas is released into the extinguisher shells, fluidizing and discharging the dry chemical agent. Each extinguisher shell is connected to a separate battery, squib, and nitrogen cartridge; however, all the sensors are wired in series so that if any one sensor detects a fire, all four extinguishing systems will discharge. This design option was selected to prevent a small fire from spreading to unaffected parts of the machine. Manual actuation is provided in the cab and on the operator's deck.

The system was installed on a Clark 675 loader operating at the Kellerman mine near Tuscaloosa, Ala. The installation required approximately 32 man-hours of labor. The system was test fired twice, once immediately following

FIGURE 19. - Test of large front end loader fire protection system.

the installation and a second time following a 1-year endurance test. Both discharge tests were successful with good dry chemical coverage in all hazard areas (fig. 19).

Thermal Sensing, Stored-Pressure Suppressant

The second fire protection system developed for front end loaders featured operator warning, greater operator control, and supervised detection and actuation circuits as well as automatic actuation. Because both cartridge-activated and stored-pressure dry chemical extinguishers are commonly used for industrial fire protection, this design allowed the use of either extinguisher type. Also, either spot-type or thermistor-strip thermal sensors could be used. The system that was actually fabricated and tested utilized stored pressure extinguishers and spot-type, rate compensation thermal sensors (fig. 20).

The system's dash-mounted control panel assembly consisted of an ON-OFF-TEST/RESET switch, audible and visual fire warning indicators, and a manual discharge button (fig. 21). If any one of the thermal sensors sensed a fire, the red FIRE warning illuminated and an audible alarm sounded. The system automatically discharged the agent after a 10-second delay, during which time the driver could stop, shut down the engine, and test the system for malfunctions.

Moving the panel switch to TEST/RESET during the delay would delay the discharge 10 seconds longer.

Discharge could be initiated immediately by striking the manual discharge button. The control panel did not have to be in the ON position because the battery supplied power directly. A remote system discharge switch mounted at

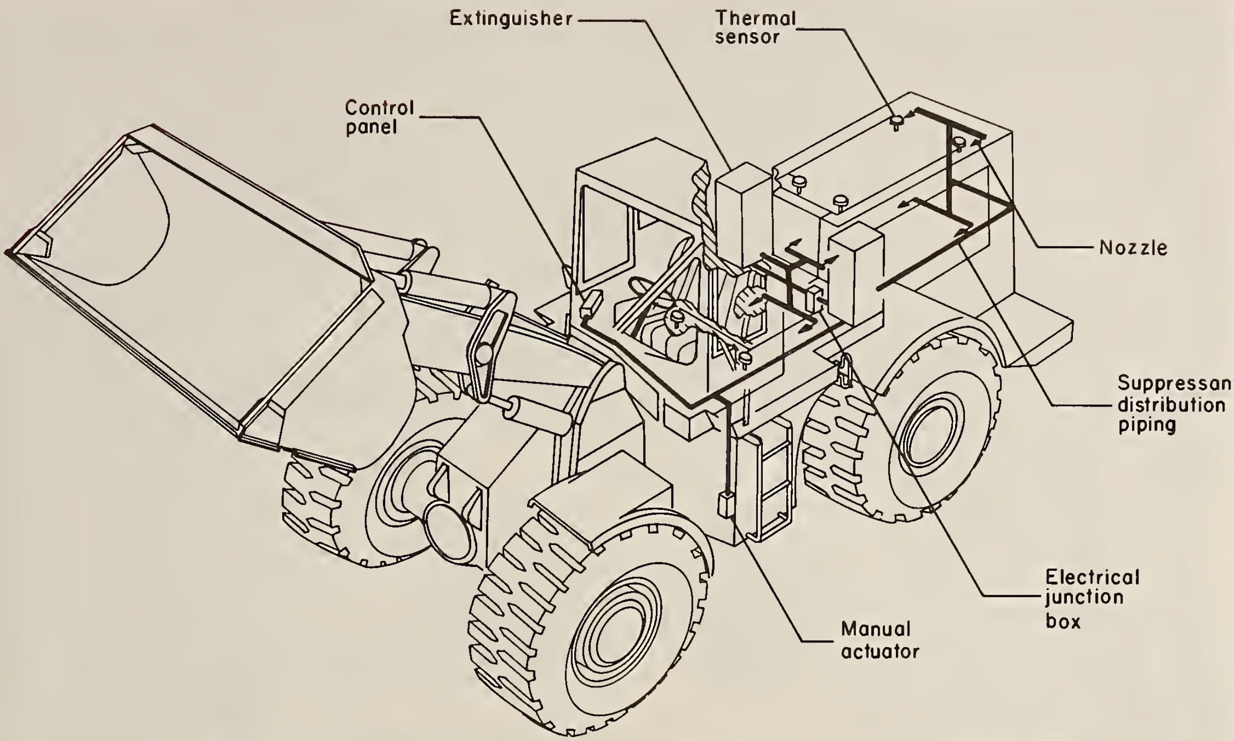

FIGURE 20. - Automatic fire protection system for large front end loaders.

the rear of the loader at ground level permitted manual actuation of the system without any fire signals, regardless of the position of either the control panel switch or the loader's master switch. The integrity of the control circuit was constantly monitored and the operator was alerted to any electrical malfunction by a yellow light and a pulsing horn.

The six thermal sensors were mounted in the engine and transmission areas. These areas were identified as prime fire hazard zones due to the presence of large amounts of flammable liquids, wire insulation and hose, and such ignition sources as electrical components and hot engine or transmission surfaces. Four 225° F sensors were mounted in the upper four corners of the engine area. The two remaining sensors were mounted in the transmission area. Because this area operated at higher normal operating temperatures than the open engine space, 325° F sensors were used.

Two stored-pressure cylinders, each containing 30 pounds of ABC dry-chemical extinguishing agent, were mounted on the operator's platform. The four nozzles from each cylinder were mounted on the engine hood. Six 180° fan-type nozzles pointed toward the engine with the discharge flow divided over top and bottom. Two nozzles pointed forward into the transmission area. Removing two 3/4-inch hose connections separated the nozzle manifold from the hood for engine maintenance.

This system was designed, fabricated, and installed on a Caterpillar 992 loader at the Jim Bridger surface coal mine near Rock Springs, Wyo., by

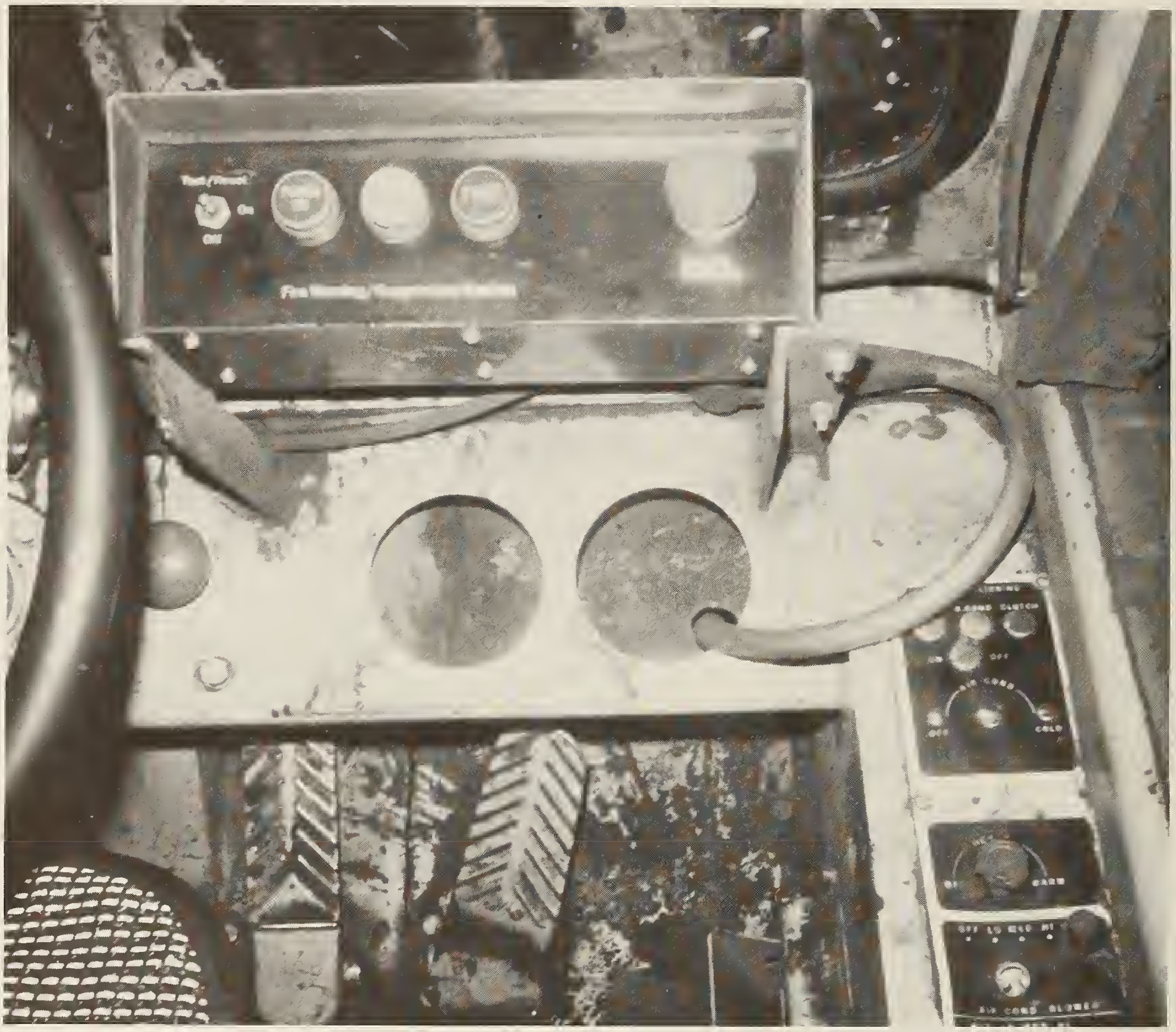

FIGURE 21. - Dashboard-mounted fire protection system control panel.

the FMC Corporation under a 1977 Bureau contract. This system underwent an endurance test on the loader for 10 months. During the first four months, both extinguishers lost significant pressure. This loss was attributed to leaking Teflon seals. These were replaced with cast urethane seals and no further leaking was observed. Automatic fire protection systems for loaders are available from several suppliers for from $1,700 to $2,600, installed.

Blasthole Drills

The Bureau has developed and tested automatic fire protection systems for two types of blasthole drills commonly used by the surface mining industry: (1) smaller, open-deck diesel drills and (2) larger electric drills with enclosed machinery houses.

Open-Deck Drills

Fire hazard areas on open-deck blasthole drills include the diesel engine, hydraulic pumps, compressors, controls, and miscellaneous class A materials such as electrical insulation, coal dust, and debris. The most severe fires generally are caused by ruptured high-pressure lines which spray combustible fluids onto hot surfaces, often igniting secondary combustibles as well. Safe operator egress is often impaired by such fires.

The Bureau developed and tested an automatic fire sensing and suppression system for open-deck blasthole drills. The system design features spot-type, fixed-temperature thermal fire sensors and multipurpose dry chemical extinguishant. The sensors are positioned above the engine and compressor areas (fig. 22). They are designed to close an electrical circuit when exposed to a temperature in excess of 300° F. Automatic discharge of the system is accomplished with an actuation device similar to that tested on the loader, but with certain design refinements.

In the event of fire, current is supplied directly from a 6-volt battery (independent of the vehicle's electrical system) to a squib. The expanding gases from the squib charge causes a pin to pierce a brass seal on a high-pressure nitrogen gas cartridge (fig. 16). The gas then discharges the dry chemical suppressant from the extinguisher shells. Each extinguisher shell is connected to a separate battery, squib, and nitrogen cartridge; however, all the sensors are wired in series so if any one detects a fire, both

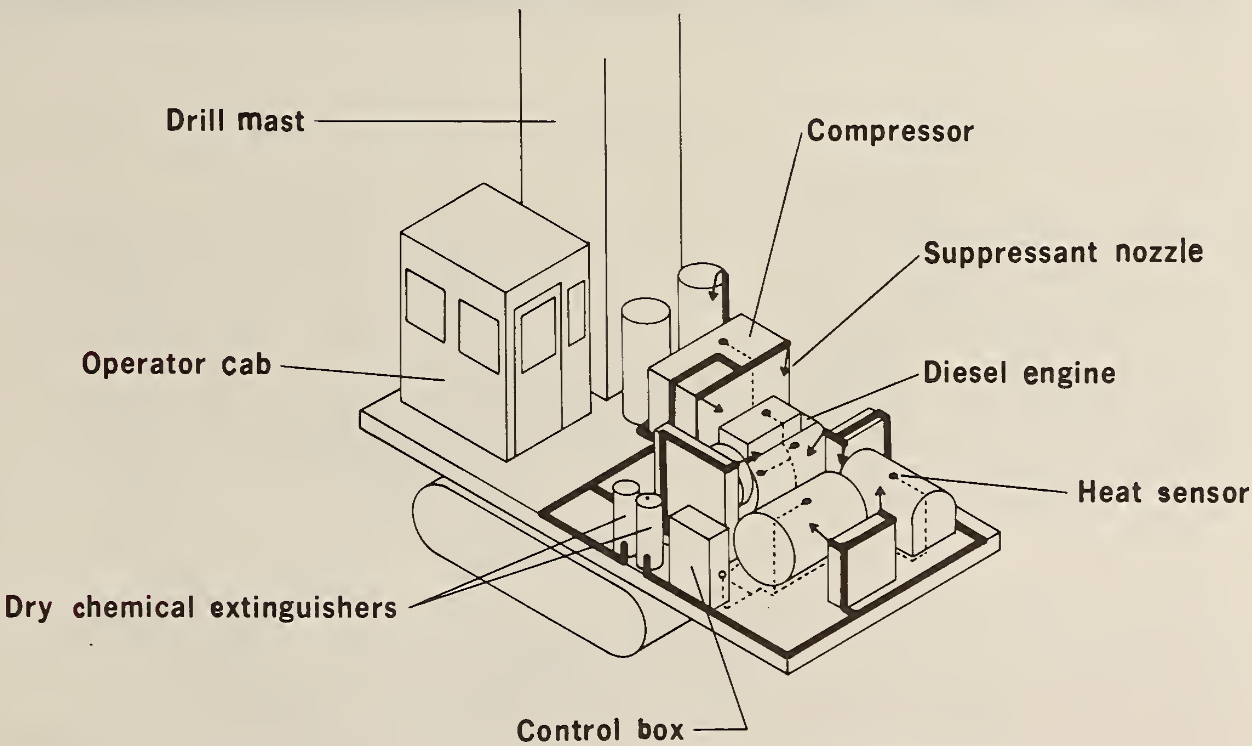

FIGURE 22. - Automatic fire protection system for open-deck mining drills.

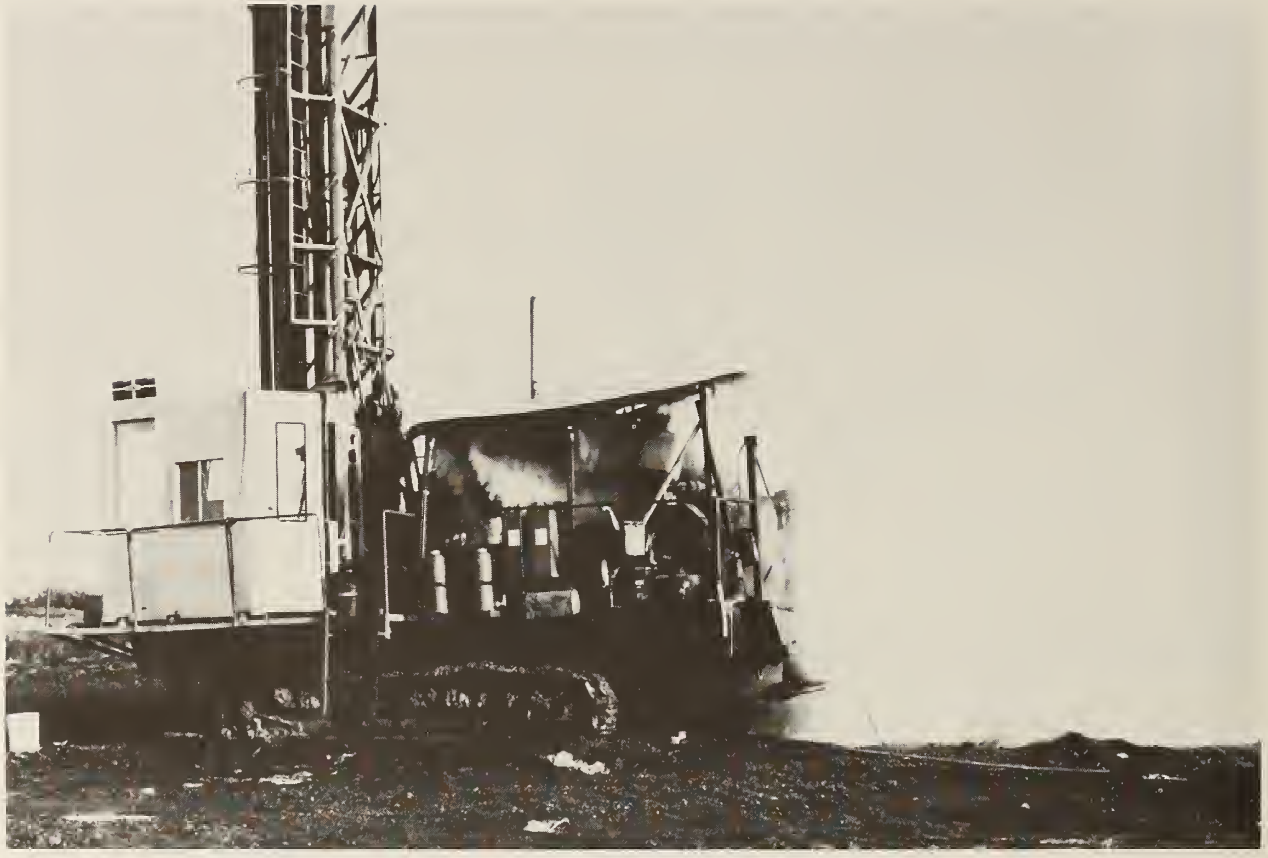

FIGURE 23. - Test of open-deck mining drill fire protection system.

extinguishing systems discharge. Manual system actuation capability is provided in the cab, on the deck, and at ground level.

The system was installed for an endurance test on a Bucyrus-Erie 30R drill operating at AMAX's Ayrshire mine near Evansville, Ind. This machine is principally used for drilling coal. Installation of the system required approximately 40 man-hours of labor. It was functionally tested immediately after installation and again after a 1-year endurance test. Both discharges were satisfactory, with powder deposited from 1/32 to 1/4 inch in all protected areas (fig. 23). During the endurance test period, the system was partially dismantled for normal drill maintenance and reassembled by mine maintenance personnel without supervision. No operational problems with this system were encountered.

Enclosed Electric Drills

Large, enclosed, electrically powered blasthole drills present complex fire protection problems. The machinery house and operator cab contain high-voltage electrical apparatus, so an electrically conductive agent such as water or foam cannot be used safely. These areas also contain delicate electrical switching gear, which would be severely damaged by the residual deposits of dry chemical if that agent was used. However, these areas are

completely enclosed, so a "clean," electrically nonconductive gas-type agent like CO_2 (carbon dioxide) or Halon 1301 (bromotrifluoromethane) can be used safely and effectively. Because of the life safety hazard of using CO_2 in an enclosed, occupied area, Halon 1301 was preferred. On most machines, the transformer room is not adequately enclosed for Halon because the floor is made of an expanded metal material that allows leaking dielectric fluids to drain to the ground. However, the transformer room does not house delicate electrical switching gear, so use of a dry chemical agent can be permitted. Therefore, the optimum fire protection system design for most enclosed, electrically powered drills requires both dry chemical and Halon 1301.

In June 1976, the Bureau contracted for installation and in-mine testing of a system based on the above conceptual design (fig. 24). The hardware was assembled and installed on a BE 61R drill operating in the Ayrshire mine near Evansville, Ind.

The system offers automatic activation with manual override controls, and uses spot-type, rate compensation thermal sensors to detect fires. Operation of the dry chemical subsystem is identical to that on the open-deck drill system described previously. Operation of the Halon 1301 subsystem is more complex because of the nature of the agent. When any sensor in the operator cab, hydraulics room, or machinery house reaches a temperature of 300° F, the Halon 1301 system automatically begins an actuation sequence. First, a bell sounds to warn the operator and the machine is automatically shut down through the ground fault interrupter circuit. After a 40-second delay, a horn sounds and 50 lb of Halon 1301 is discharged through a solenoid-operated valve to nozzles in each area. The 40-second delay is necessary to allow time for

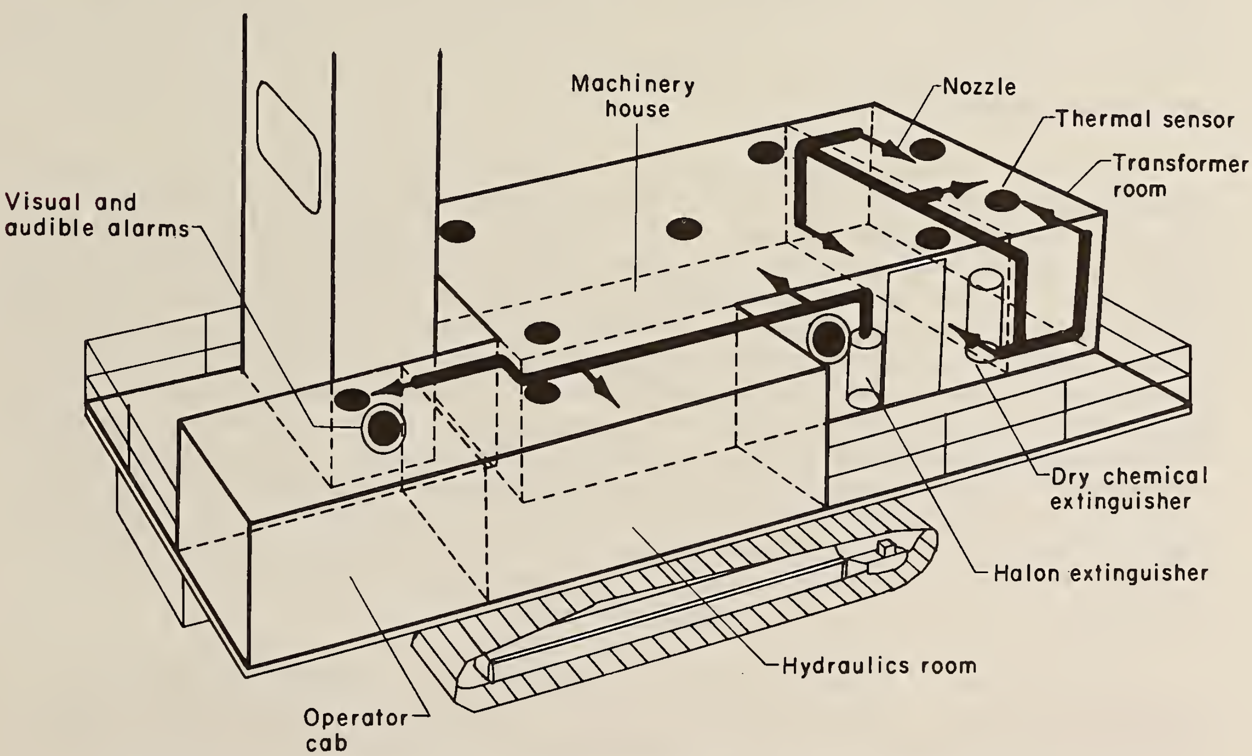

FIGURE 24. - Automatic fire protection system for large enclosed blasthole drills.

the ventilation fans to stop completely to avoid blowing the Halon gas out of the machine.

The system was designed to induce a minimum 5 vol-pct concentration of Halon 1301 as required by NFPA 12A. The maximum Halon 1301 concentration allowed by NFPA 12A is 7 pct for total flooding systems in normally occupied areas where egress cannot be accomplished in 1 min. Where egress can be accomplished in less than 1 min, a 10 pct maximum concentration is allowed. Research has demonstrated that lower effective extinguishing concentration for Halon 1301 to be 2.5 pct for PVC wire insulation (1) and transformer oil (7).

Following installation, a Halon discharge test was performed to measure agent concentrations in the operator cab, hydraulics room, and machinery house. Gas concentrations were measured in all three rooms with a Cardox Halon Analyzer. The concentration was excessive in the cab, but insufficient in the machinery house. The low machinery-house concentration was attributed to the many unclosable openings in this area such as ventilation louvers, fan openings, and pipe and cable runs.

To correct these problems, the operator cab nozzle orifice was reduced and a second "make-up" Halon bottle was added to the system. The actuation sequence was then modified to discharge the 20-lb "make-up" bottle approximately 1-1/2 min after the 50-lb primary discharge to boost the concentration in the machinery house. These system design changes were tested and resulted in satisfactory concentrations of from 2.5 to 7 pct for about 4 min in all three areas. After an approximate 1-year endurance test, the system was again discharge-tested to measure agent concentrations. Concentration varied from 2.5 to 8.5 pct for 2 to 6 min in the machinery house with slightly lower values in the other two areas (fig. 25). Although the design concentrations were achieved, the soaking time may not have been adequate to extinguish certain class A materials.

In an effort to lengthen the Halon soaking time without causing unsafe (high) agent concentrations, a research contract was issued to test an extended discharge Halon valve. This system, tested on a Bucyrus-Erie 61R drill, also utilized two Halon bottles. However, unlike the design described above, both a 46-lb primary charge and a 19-lb make-up charge are discharged simultaneously. In this case, the make-up bottle is connected to the primary-agent-distribution piping network through a metering orifice. Halon flow through this tiny orifice is matched closely to the estimated rate of escape of Halon through the unclosable openings in the drill. In this way, a more consistent Halon concentration can be maintained over a longer time period. In tests of the extended discharge system, Halon concentrations of 2.5 to 7 pct were maintained in the machinery house for more than 10 min (fig. 26). Measured concentration in the hydraulics room dropped below 2.5 pct after about 2 min. Actual concentrations were probably slightly higher owing to the extreme elevation of the sampling points.

In addition to measuring agent concentrations, these tests involved extinguishing test fires with the system. Two steel fire test cannisters, approximately 5 in tall by 3 in in diameter, containing a cleaning solvent

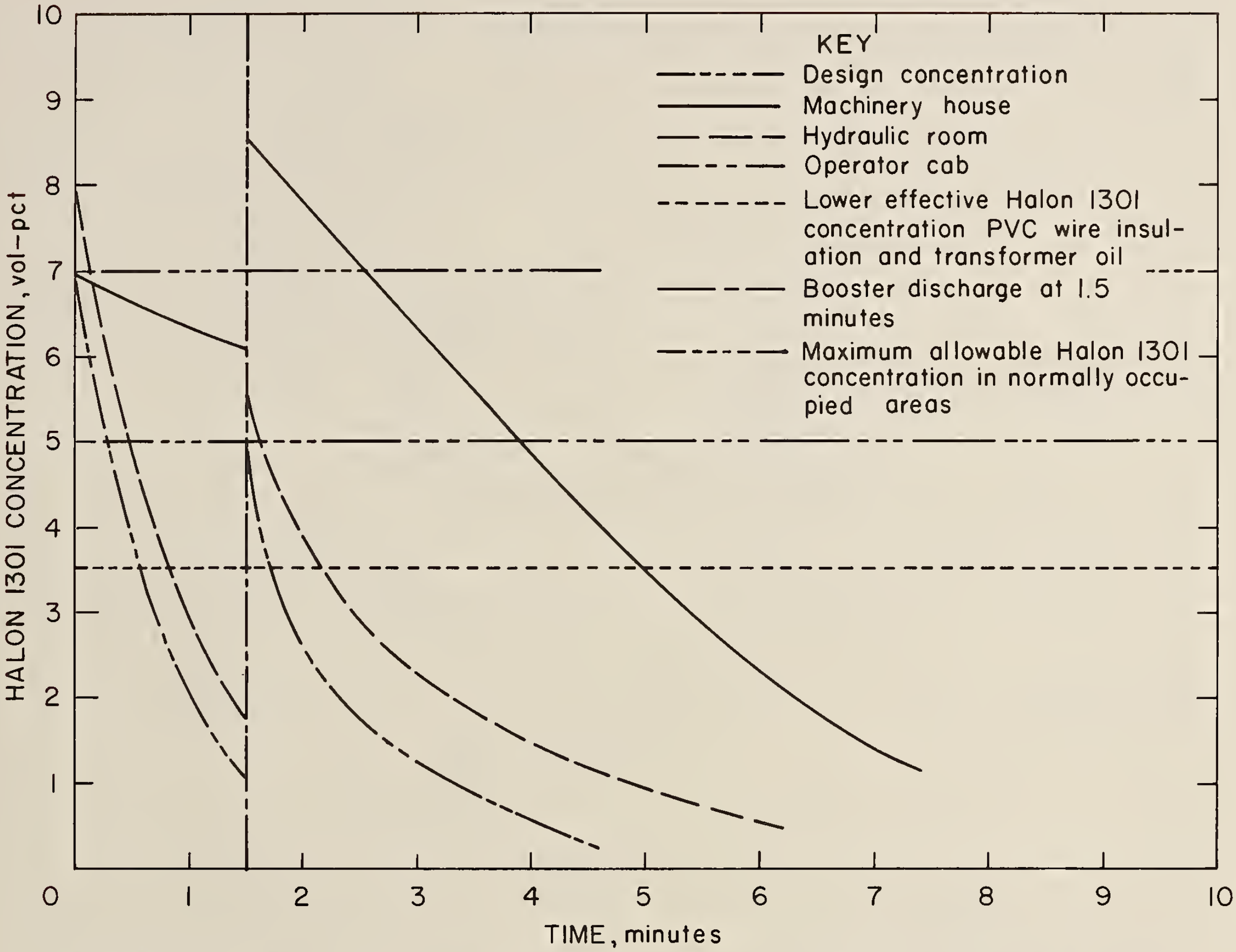

FIGURE 25. - Halon 1301 concentration test results using delayed discharge technique (blasthole drill).

used on the drill, were placed in the operator's cab and hydraulic enclosure. A third cannister approximately 8 in tall by 5 in in diameter containing cleaning solvent and a bundle of plastic insulated electrical wire was placed in the machinery house. The fires were allowed to burn for about 3 min, then the system was manually discharged. All three fires were extinguished in 8 to 10 seconds from the start of the discharge. Extinguishment of these test fires is indicative of the suppression capability of the system in an actual fire situation. After a 2-year endurance test period, no operational failures of this system have occurred. These automatic fire protection systems for blasthole drills are now available commercially and vary in cost from $1,700 to $3,500.

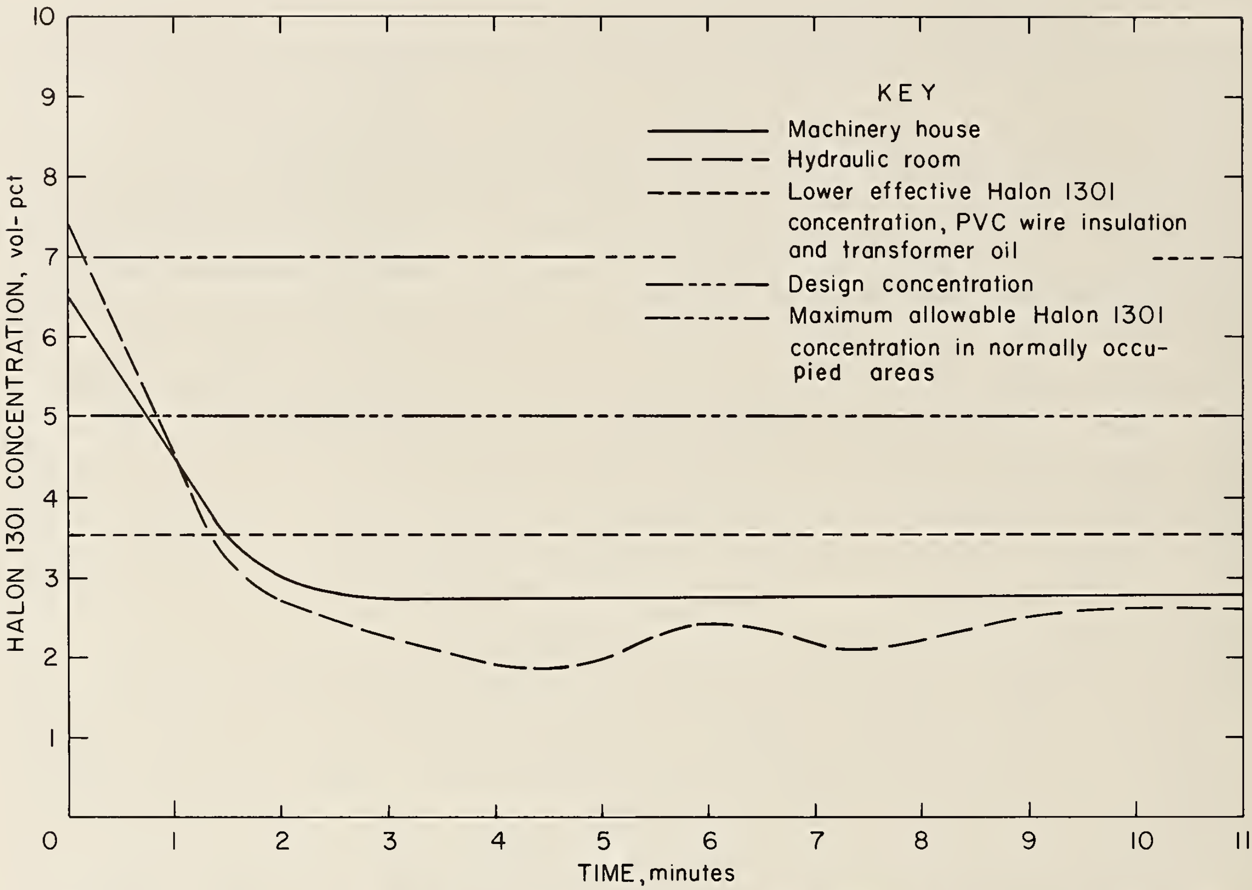

FIGURE 26. - Halon 1301 concentration test results using extended discharge valve technique (blasthole drill).

Diesel-Hydraulic Shovels

Fire protection on hydraulic shovels is essential because of the presence of large amounts of combustible hydraulic fluids and diesel fuel at high temperatures and pressures. A thorough analysis of the fire hazards on these shovels was conducted to determine which areas most needed protection. The rear upper structure of the machine, which houses the diesel engine and hydraulic pumps, was designated the primary hazard zone because it has excessive loading of fuels and such ignition sources as exhaust manifolds, blowers, and frictional heat sources. The ring gear area where grease can accumulate was designated a secondary hazard zone because fires originating in other parts of the machine could spread to this area. The design developed called for protection in both hazard zones.

The system included a thermistor core, thermal wire sensor strung throughout the rear upper structure; a cartridge-operated, eight-nozzle dry chemical suppression system; supervised sensing and actuation circuits with manual override controls in the cab and at ground level; and automatic engine shutdown upon system actuation (fig. 27).

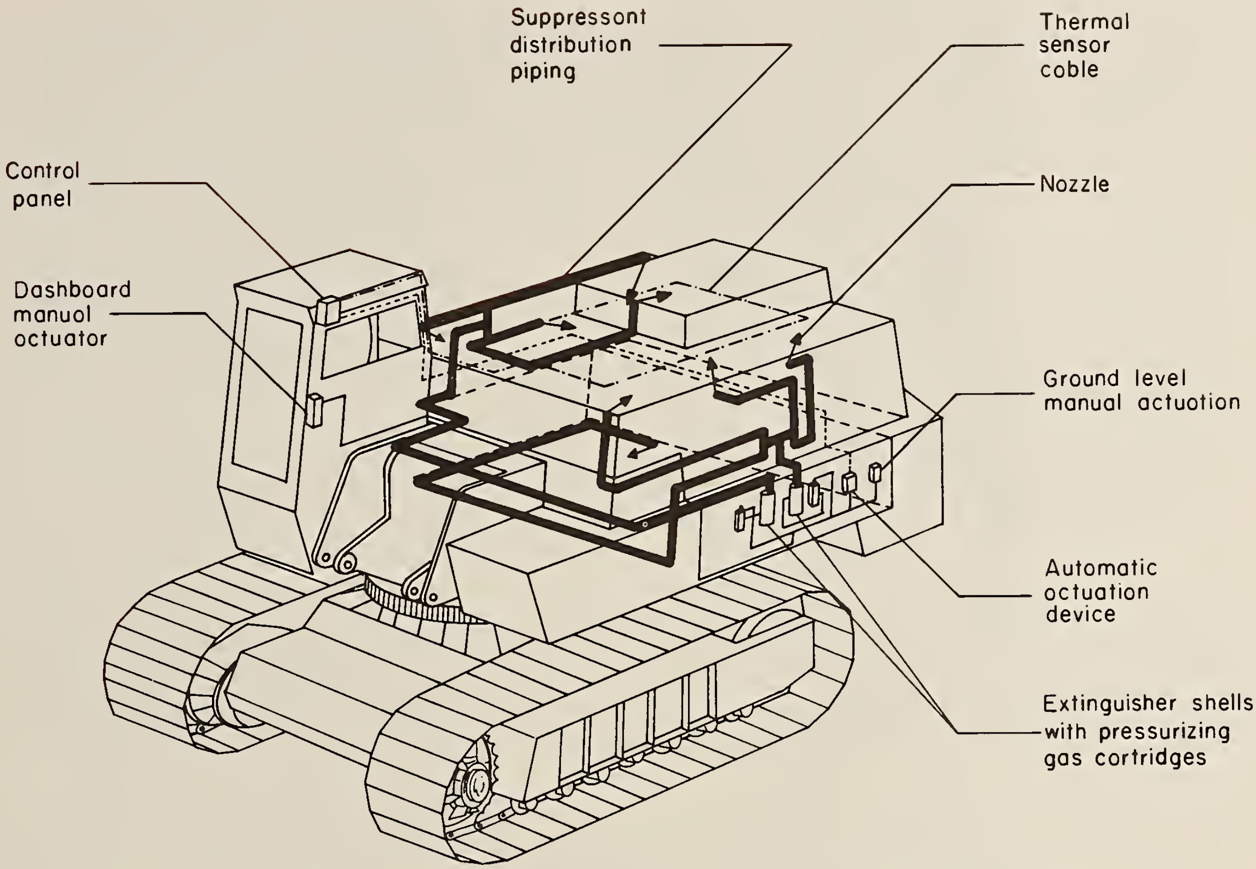

FIGURE 27. - Automatic fire protection system for hydraulic shovel.

The fire sensor is the same as that used on the ash hauler. It consists of two electrical conductors housed in a thin steel casing. The conductors are separated by a thermistor material whose resistance varies inversely with temperature. The resistance between the two wires is monitored by the system's control panel. This type of thermal sensor has been commercially available for many years and is commonly used in military, aerospace, and other rugged applications. When the cable is exposed to a temperature of 240° F, a current is supplied to the suppression system actuation device. This actuation device (fig. 28) consists of a puncture pin fixed to a piston. Also attached to the piston is a spring held in compression by the magnetic attraction between the piston and a permanent magnet. When a current is supplied to the actuation device, an electromagnet energizes, disrupting the field of the permanent magnet and releasing the piston. The puncture pin fixed to the piston pierces the seal of a high-pressure nitrogen gas cartridge. The gas thus released pressurizes the suppression system's pneumatic actuation circuit and 40 lb of multipurpose dry chemical fire suppressant is expelled through fixed distribution lines to eight nozzles located in the rear upper structure and ring gear area. The vehicle batteries supply the 12-volt electrical power for system operation. The control panel circuits are completely supervised to warn the operator of any electrical malfunctions in the system. Manual override controls are in the cab and at ground level. The actuation circuit

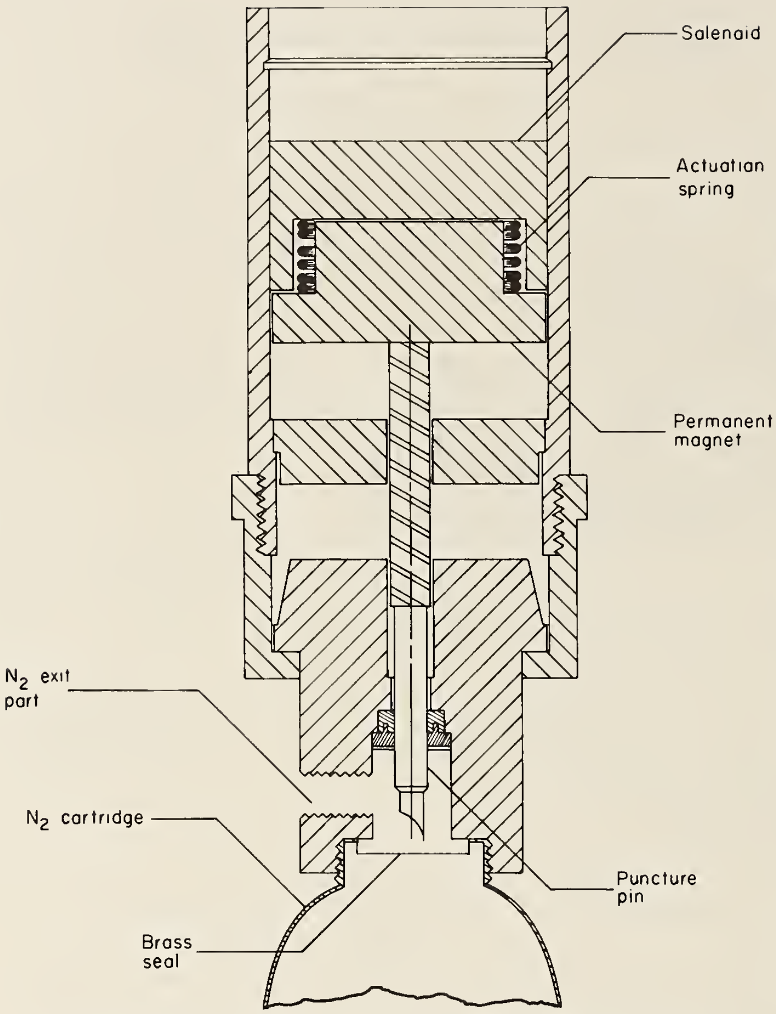

FIGURE 28. - Magnetic latch-type actuator for fire suppression systems.

also is fitted with an interlock to shut down the engine in the event of fire.

The complete system was installed on a Poclain HC300 hydraulic shovel at Pittsburg and Midway Coal Co.'s Empire mine near Pittsburg, Kans. The system underwent 1 year of endurance testing without failure.

Electric Mining Shovels

Primary fire hazard areas on electric mining shovels are the electrical apparatus and lubricants in the machinery house and the roller path/collector ring area inside the crawler base. A fire in either of these areas could impede safe operator egress and result in considerable property damage. A research contract was awarded to develop and in-mine fire test an automatic fire protection system for electric loading shovels.

The suppression system design requirements for the machinery enclosure of a mining shovel were analyzed. Because the possibility of human occupancy exists during shovel maintenance work and periodically during machine operation, only fire control agents that are nontoxic when used in recommended fire extinguishing concentrations could be considered. The presence of electric controls and equipment (in some instances solid state controls) also demands consideration of agent residue removal. A gaseous agent such as Halon 1301 satisfies both toxicity and cleanliness requirements. However, almost complete enclosure integrity must be insured if Halon alone is to be used safely and effectively, and significant differences exist in the degree of enclosure integrity between the various shovel types and sizes. The rope opening, the major unclosable opening in the machinery enclosure, can vary from a 4- to 5-sq-ft area to an area several feet wide and extending the height of the machine.

Two alternatives for protection of mining shovel machinery spaces were developed. Where enclosure is adequate, a Halon 1301 system is recommended.

In cases where the cable opening size prohibits use of a gaseous agent alone, dry chemical is used to protect the main room while Halon 1301 is piped into the electrical enclosures. This arrangement insures complete agent penetration in these enclosures and also prevents dry chemical from contacting electrical controls. This eliminates a significant portion of the cleanup effort. In either design alternative, the suppression system is designed to totally flood a 5 pct minimum concentration of Halon 1301 and maintain an extinguishing concentration for approximately 10 minutes. To compensate for the unclosable ventilation openings and rope opening, the concentration is maintained through application of the extended discharge technique described in NFPA 12A, A-2-5.3. The extended discharge is provided by a separate Halon supply connected to the distribution piping through a metering orifice. The orifice is sized to correct for the anticipated leakage through unclosable openings. The length of the extended discharge will vary from approximately 8 to 10 minutes, depending on the initial pressure and temperature of the storage cylinder. Environmental and operating conditions support the use of fixed-temperature thermal detectors to sense the fire.

In operation, both systems shut down the ventilation system and sound an audible alarm upon detection of a fire. Following a delay to allow the operator time to safely stop the motion of the shovel and evacuate the machine, power is removed via the ground fault system and the agents are released. The alarm continues to function until disconnected from the emergency power supply.

Protection of the collector ring area beneath the machinery deck is best accomplished with dry chemical because of this area's open construction. Detection, agent storage, and distribution are dependent on access to the collector ring area and power, if available in the crawler base.

A system conforming to these conceptual design criteria was fabricated and installed on a Bucyrus-Erie 150B shovel operating in the Peabody Coal Co., Lynnville mine near Evansville, Ind. (fig. 29). The particular machine selected for tests offered adequate enclosure integrity for Halon 1301 to be used alone in the machinery house.

The Halon storage reservoirs are DOT 4BW-500 cylinders equipped with differential pressure valves. The initial discharge cylinder, containing 90 lb of Halon 1301, is equipped with a solenoid actuator. Two extended discharge cylinders, containing 75 lb each of Halon 1301, are equipped with slave pneumatic operators. Both extended-discharge cylinders discharge to a common orifice plate located in the distributing piping.

Fire detection is provided by 190° F spot-type, rate compensation thermal fire detectors. The detectors are above the motor-generator sets, the lubrication storage area, the main transformer cabinet, and centrally above the rope-handling machinery. Manual actuators are in the operator's enclosure and near the main exit from the machinery house. Alarm horns are within the machinery and operator enclosures. Also controlled are the ventilation and equipment shutdown and three magnetic door holders. Because of the particular ventilation arrangement of this machine, the doors must be open during periods of warm weather. The function of door holders is to hold the doors in the

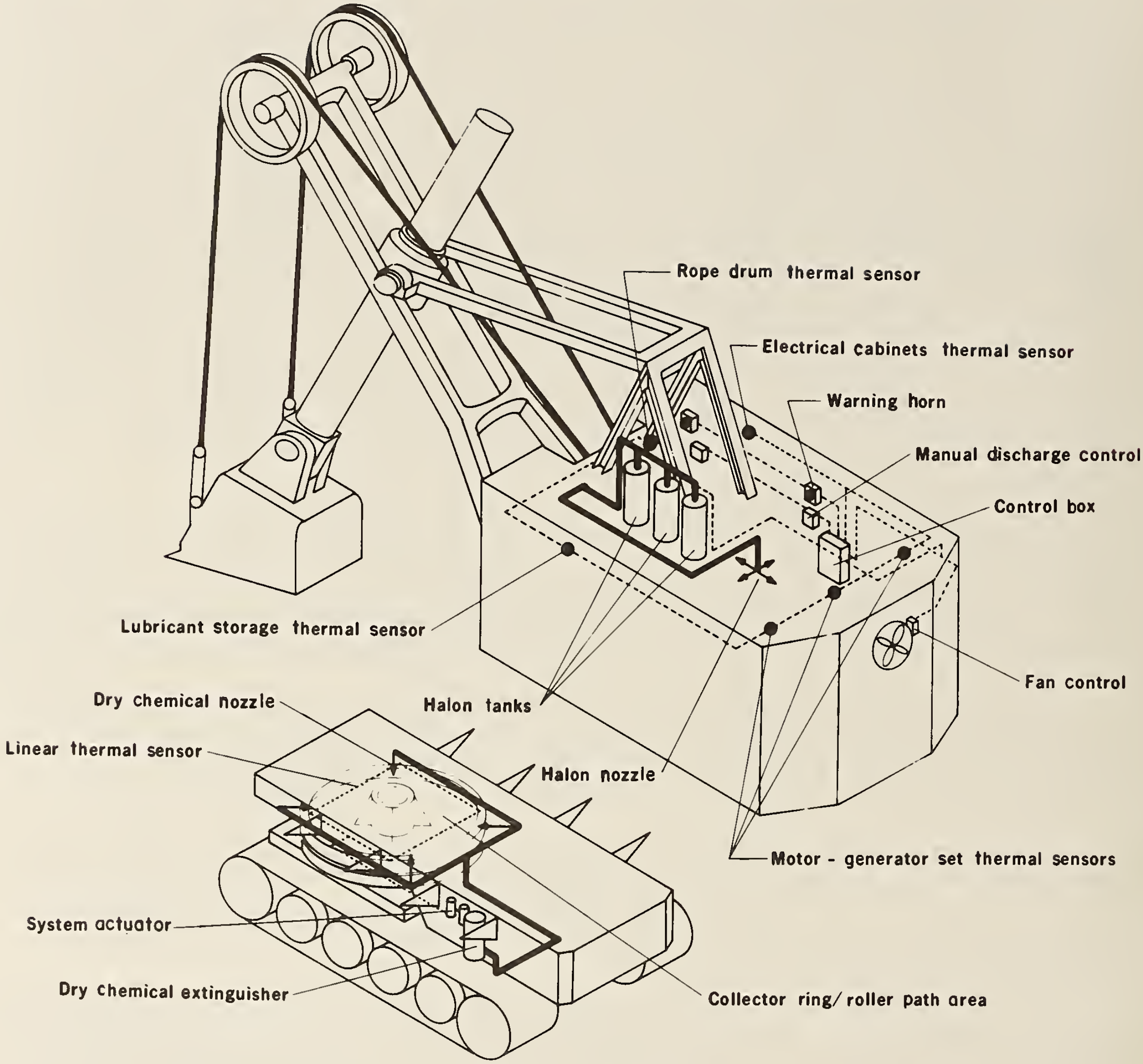

FIGURE 29. - Automatic fire protection system for an electric mining shovel.

open position when desired. When activated, the magnetic holders release the doors, which are then closed by spring hinges. At all times, the doors can be manually released by pulling them away from the holder.

The Halon system distribution piping system is described in figure 25. It contains approximately 30 ft of 1½-inch piping and one centrally located Halon 1301 nozzle. The nozzle and piping are hydraulically balanced to provide an initial discharge of less than 10 sec. The piping also distributes the agent during the extended discharge.

The collector ring system supplies 20 lb of multipurpose dry chemical to four nozzles through hydraulic hose. The chemical storage container,

distribution hose, and nozzles are mounted on the revolving frame of the shovel, and are installed to flood the volume housing the collector rings and center pin by injecting the chemical above the shovel swing rollers. Each nozzle produces an approximately 180° flat pattern which, when aimed at the center pin from the four nearly equally spaced points, assures complete coverage.

The dry chemical system detection and actuation device is a self-contained pneumatic unit employing heat-sensitive pneumatic tubing for detection. This is the same system described earlier for the haulage truck (p. 12). The two main components of the system are the pressure make-up device (PMD) used to pressurize the detection tubing, and the detection actuation device (DAD).

Upon rapid loss of pressure in the detection tubing, which bursts when exposed to a temperature of 355° F, the DAD punctures a nitrogen cartridge and sends a pneumatic actuation signal to the dry-chemical suppression system. A pressure-operated electrical switch, installed in the detection line, also reacts to a rapid pressure drop and sounds alarm horns in the operator cab and machinery enclosure.

The installed Halon suppression system was fire tested at the Lynnville mine after a 1-month shakedown period. As part of this test, two fire canisters, approximately 8 in tall by 5 in in diameter were placed in the machinery enclosure. Cleaning solvent and wiring in the canister were ignited and allowed to burn until established (fig. 30). The system was then actuated using the pull station located near the exit from the machinery enclosure. Immediately upon actuation, the alarms sounded, the doors closed, and the ventilating fan was shut down. Following a 30-second delay, the motor-generator sets were shut down and the Halon discharge began. The test fires were completely extinguished in 8 to 10 seconds after the discharge started (fig. 31). The concentrations during the initial and extended discharge period were recorded on a Cardox Halon analyzer from sampling points near the ceiling of the compartment, one approximately midway along the side of the enclosure, and the other at the rear of the machine near the fan opening.

The initial discharge quickly achieved the design concentration. (The test fires were extinguished in 8 to 10 sec after the start of the discharge.) However, during the extended discharge, the concentration fell quickly to approximately 2.5 pct (fig. 32). The most probable causes for the drop in measured concentration are the height of the sampling points and the failure to account for the combined effects of the smaller openings.

After 1½ years of continuous use on the shovel, no operational system failures have occurred. Automatic systems based on this and similar designs are now commercially available from several suppliers for about $5,500.

FIGURE 30. - Test fire burning in a mining shovel machinery house.

FIGURE 31. - Test fire extinguished by discharge of Halon 1301.

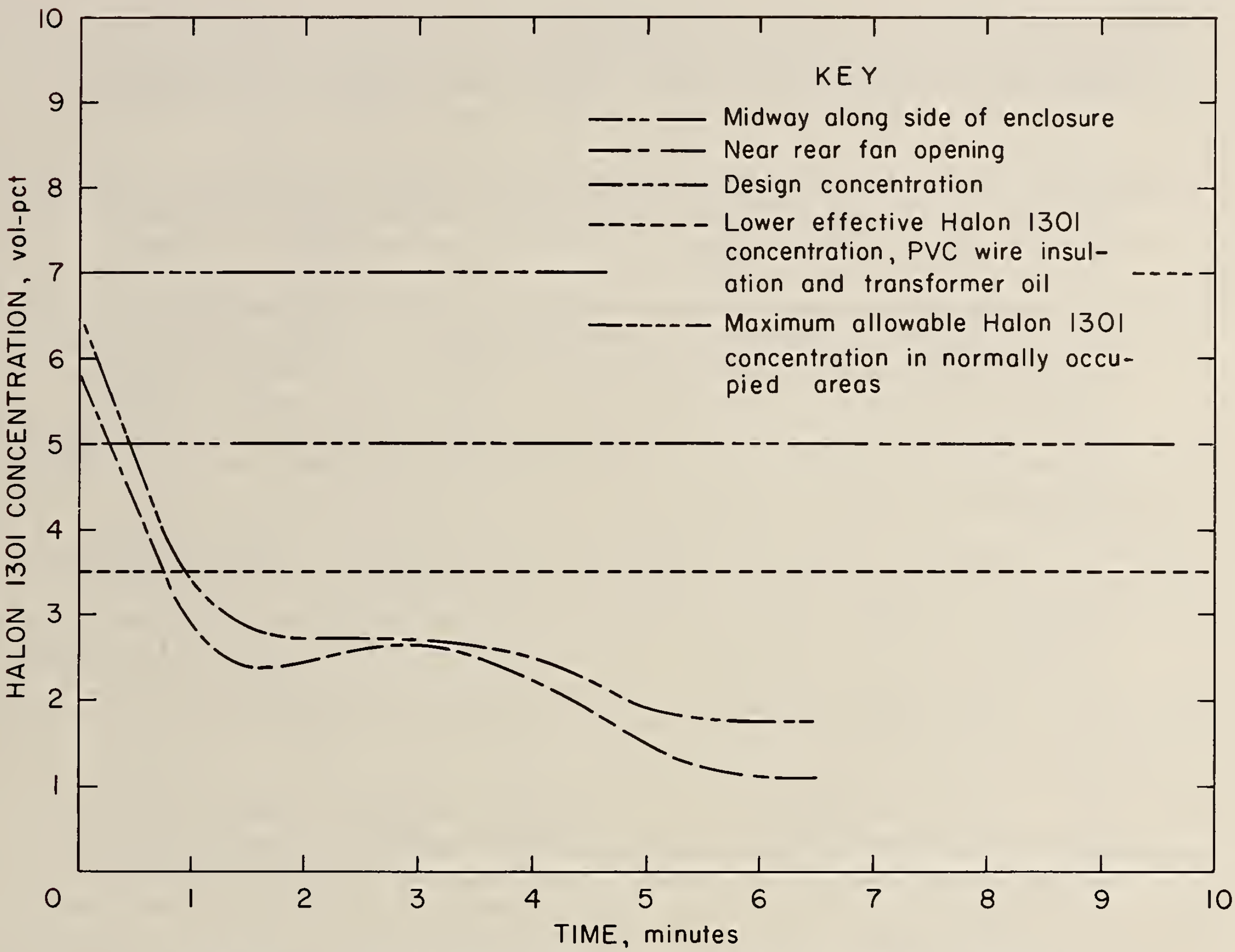

FIGURE 32. - Halon 1301 concentration test results in the mining shovel.

SUMMARY AND CONCLUSIONS

Fires on mobile surface mining equipment are a serious safety hazard and interfere with normal mine production. Automatic fire sensing and suppression systems that use off-the-shelf components have been developed by the Bureau of Mines for this equipment. Based on in-mine trials on haulage trucks, first generation prototypes have been refined to improve their performance and modified to adapt to the specialized fire protection needs of a wide variety of mine equipment types and mining conditions. Long-term in-mine evaluations have proven the ruggedness and reliability of these systems in the harsh mining environment. Systems patterned after Bureau-developed designs are now commercially available to the mining industry. System hardware and installation costs vary from about 1 pct of equipment capital cost for haulage trucks to about 0.4 pct for electric mining shovels.

REFERENCES

1. Cholin, R. R. How Deep Is Deep? (Use of Halon 1301 on Deep-Seated Fires). Fire Journal, v. 66, No. 2, January 1972, 8 pp.

2. deLime, T. L. Improved Off-the-Road Vehicle Fire Protection. Pres. at 82d National Fire Protection Association Annual Meeting, Anaheim, Calif., May 15, 1978, 22 pp.

3. FMC Corporation, Advanced Products Division. Improved Sensors and Fire Control Systems for Mining Equipment. Phase I. BuMines Open File Rept. 25(1)-74, 1972, 252 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 232 405/AS.

4. _____. Improved Sensors and Fire Control Systems for Mining Equipment. Phase II. Final Report. BuMines Open File Rept. 25(2)-74, 1973, 178 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 232 406/AS.

5. _____. System Modification and Validation Testing of Fire Protection Systems for Mine Haulage Trucks. BuMines Open File Rept. 33-74, 1974, 170 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 234 577/AS.

6. _____. A Guide to the Selection of Automatic Fire Protection Systems for Mine Haulage Equipment. BuMines Open File Rept. 34-74, 1974, 8 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 234 575/AS.

7. Ford, C. L. An Overview of Halon 1301 Systems. Proc. ACS Symp. on Halogenated Fire Suppressants, San Antonio, Tex., Apr. 23-24, 1975, 63 pp.

8. Jewett, J. W. Fire Suppression Systems. Pres. Soc. of Automotive Engineers Off-Highway Vehicle Meeting, Milwaukee, Wisc., Sept. 5-8, 1979. SAE Technical Paper Series 790779, 16 pp.

9. Johnson, G. A., and D. R. Forshey. Automatic Fire Protection Systems for Large Haulage Vehicles: Prototype Development and In-Mine Testing. BuMines IC 8683, 1975, 16 pp.

10. _____. Improved Fire Protection Systems for Surface Coal Mining Equipment. Pres. at Society of Automotive Engineers Off-Highway Vehicle Meeting, Milwaukee, Wisc., Spet. 12-15, 1977. SAE Technical Paper 770744.

11. Kasten, A. E., G. R. Reid, and R. Plog. Develop and Test an Automatic Fire Control System for Surface Mining Machinery. Final Report, Volume I. BuMines Open File Rept. 119-78, 1977, 163 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Service, Springfield, Va., PB 293 983/AS.

12. Lease, W. D. Development and Testing of Fire Protection System for Coal Augers. BuMines Open File Rept. 25-76, 1975, 13 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 249 865/AS.

13. _____. Development, Installation, and Testing Services for an Automatic, Point-Type Thermal Sensor Fire Protection System on a Mining Dozer. BuMines Open File Rept. 71-77, 1976, 18 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 266 075/AS.

14. Pomroy, W. H. Improved Automatic Fire Protection System for Off-Highway Mine Vehicles. Pres. at Society of Automotive Engineers Off-Highway Vehicle Meeting, Milwaukee, Wisc., Sept. 5-8, 1979. SAE Technical Paper Series 790880.

15. Reid, G. R. Fire Protection System for Mobile Underground Metal Mining Equipment. BuMines Open File Rept. 111(1)-77, 1976, 235 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 268 735/AS.

16. _____. Automatic Fire Protection System for Mobile Underground Metal Mining Equipment. Selection and Use Manual. BuMines Open File Rept. 111(2)-77, 1976, 16 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 268 769/AS.

17. Roehlich, F., Jr. Demonstration of Fire Suppression Systems on Underground Mining Equipment. BuMines Open File Rept. 20-78, 1977, 68 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 278 904/AS.

18. Stevens, R. B. Automatic Fire Sensing and Suppression Systems for Mobile Mining Equipment. BuMines Open File Rept. 34-79, 1978, 166 pp.; available for consultation at Bureau of Mines libraries in Pittsburgh, Pa., Twin Cities, Minn., Denver, Colo., and Spokane, Wash., and at the Central Library, U.S. Department of the Interior, Wash., D.C. Also available from National Technical Information Service, Springfield, Va., PB 234 577/AS.

19. Stevens, R. B., and W. S. Oda (assigned to U.S. Dept. of the Interior). Fire Prevention System. U.S. Pat. 3,993,138, Nov. 23, 1976.

20. U.S. Bureau of Mines, Mining Research Staff. Metal Mine Fire Protection Research. Proc. Bureau of Mines Technology Transfer Seminar, Tucson, Ariz., March 18, 1977. BuMines IC 8752, 1977, 51 pp.

21. U.S. Bureau of Mines. Automatic Fire Protection Systems for Large Mobile Vehicles, Technology News, No. 11, 1974.

22. _____. Automatic Fire Protection for Surface Coal Augers. Technology News, No. 27, 1976.

23. _____. Bulldozer Fire Protection. Technology News, No. 50, 1978.

24. _____. Fire Protection For Blasthole Drill. Technology News, No. 70, 1979.

25. _____. Fire Protection for Front End Loaders. Technology News, No. 74, 1979.

26. _____. Loading Shovel Fire Protection. Technology News, No. 77, 1980.

27. _____. Fire Protection for Hydraulic Excavators. Technology News, No. 78, 1980.

28. _____. Automatic Fire Protection for Mining Trucks. Technology News, No. 79, 1980.

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-603-102/110

INT.-BU.OF MINES,PGH.,PA. 24878


THE LIBRARY OF CONGRESS